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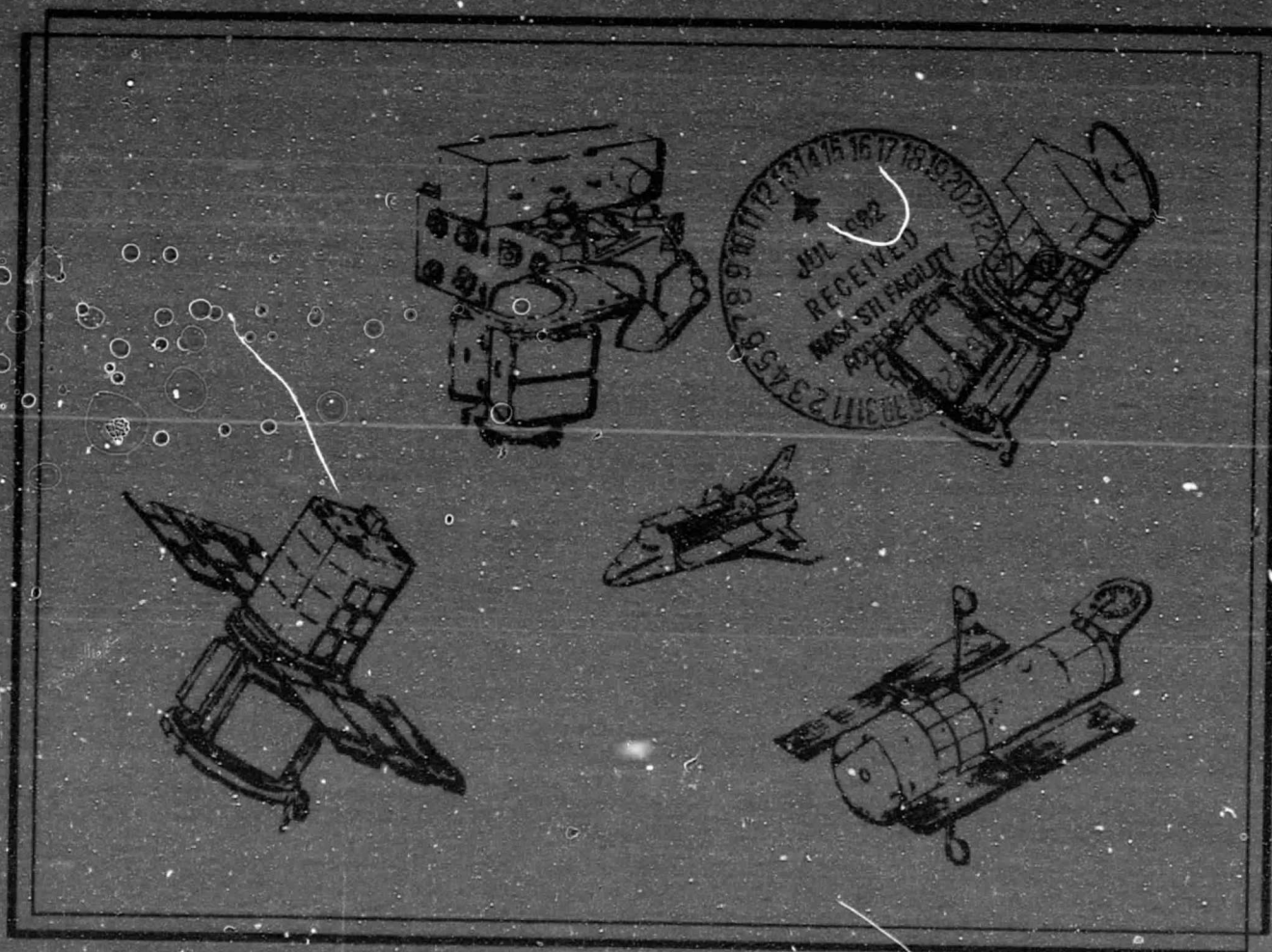
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NASA-CR-167607

SATELLITE SERVICES SYSTEM ANALYSIS STUDY

volume 1 — executive summary



GRUMMAN AEROSPACE CORPORATION

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SATELLITE SERVICES SYSTEM ANALYSIS STUDY

volume 1 — executive summary

prepared for
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Houston, Texas 77058

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Foreword

This study was conducted for the Lyndon B. Johnson Space Center and directed by Contracting Officer's Representatives (COR), Mssrs. Reuben Taylor and Gordon Rysavy. Grumman Aerospace Corporation's study manager was Mr. John Mockovciak Jr.

This final report is presented in seven volumes as follows:

- Volume 1 — Executive Summary
- Volume 2 — Satellite and Services User Model
- Volume 2A — Satellite and Services User
Model-Appendix
- Volume 3 — Service Equipment Requirements
- Volume 3A — Service Equipment Require-
ments-Appendix
- Volume 4 — Service Equipment Concepts
- Volume 5 — Programmatic

Acronyms

Abbreviations and acronyms used frequently throughout the Satellite Services System Analysis Study (SSSAS) are defined as follows:

ACS - Attitude Control System	MMU - Manned Maneuvering Unit
AFD - Aft Flight Deck	MRV - Manned Reconnaissance Vehicle
ASM - All Sky Monitor	MTV - Maneuverable Television
AXAF - Advanced X-Ray Astrophysics Facility	NOSS - National Oceanic Satellite System
CCTV - Closed Circuit Television	OAO - Orbiting Astronomical Observatory
C & DH - Command & Data Handling	OBC - Onboard Checkout
C & DL - Command & Data Link	OCC - Operations Control Center
C/O - Checkout	OCP - Open Cherry Picker
DDT&E - Design, Development, Test & Evaluation	OMS - Orbital Maneuvering System
DoD - Department of Defense	PAM A - Payload Assist Module (type) A
DOF - Degrees of Freedom	PAM D - Payload Assist Module (type) D
EMU - Extra-Vehicular Mobility Unit	PIDA - Payload Installation & Deployment Aid
EVA - Extra Vehicular Activity	PM I/II - MMS Propulsion Module I & II
FSS - Flight Support System	POCC - Payload Operations Control Center
GAC - Grumman Aerospace Corporation	POM - Proximity Operations Module
GEO - Geosynchronous Earth Orbit	RCS - Reaction Control System
GRAVSAT - Earth Gravity Field Survey Mission	RMS - Remote Manipulating System
GRO - Gamma Ray Observatory	ROM - Rough Order of Magnitude
GSE - Ground Support Equipment	S/C - Spacecraft
HEAO - High Energy Astronomy Observatory	SE&I - System Engineering & Integration
HPA - Handling & Positioning Aid	SMM - Solar Maximum Mission
IR - Infrared	SRM - Solid Rocket Motor
IRAD - Independent Research and Development	SSS - Satellite Services System
IUS - Inertial Upper Stage	SSSAS - Satellite Services System Analysis Study
IVA - Internal Vehicular Activity	S/S - Subsystem
JSC - Johnson Space Center	S/SUM - Satellite and Services User Model
KSC - Kennedy Space Center	STE - Special Test Equipment
LAPC - Large Area Proportional Counter	STS - Space Transportation System
LASS - Large Amplitude Space Simulator	TDRS(S) - Tracking & Data Relay Satellite (System)
LASSII - Low Altitude Satellite Studies of Ionospheric Irregularities	TMS - Teleoperator Maneuvering System
LEO - Low Earth Orbit	TV - Television
LOS - Line-Of-Sight	UARS - Upper Atmospheric Research Satellite
MDF - Manipulator Development Facility	UV - Ultraviolet
MFR - Manipulator Foot Restraint	VSS - Versatile Service Stage
MMS - Multimission Modular Spacecraft	WBS - Work Breakdown Structure
	WETF - Weightless Environment Training Facility
	WIF - Water Immersion Facility
	WRU - Work Restraint Unit
	XTE - X-Ray Timing Explorer

1 – Introduction

Satellite services is an extension of the Space Transportation System (STS) which will provide on-orbit services and operational capabilities that exploit the uniqueness of the STS (vs expendable launch vehicles) and the advantages of human presence on-orbit. Within the capabilities of the Space Shuttle Orbiter, a broad range of services can be made available to the satellite user community including deployment, examination, retrieval, earth return, and direct on-orbit repair and maintenance.

The nature of on-orbit services has indicated that standardization of on-orbit operations/equipment usage be employed to minimize user charges/cost of operations and to maximize mission success prospects. Thus, the service needs

have been addressed in the context of an integrated, centrally-managed "system," as opposed to a single purpose, satellite-unique approach. As shown in Fig. 1-1, satellite services can be viewed as the bridge between the STS and the satellite user community. The Satellite Services System (SSS) involves effective integration of the Orbiter crew, service equipment, simulation/training, and flight operations planning.

This study has addressed the preliminary definition of the SSS concept, and provides information to satellite users relative to the types of service equipment and servicing modes that would accomplish the functions of deployment, examination, retrieval, earth return, and direct on orbit repair and maintenance.

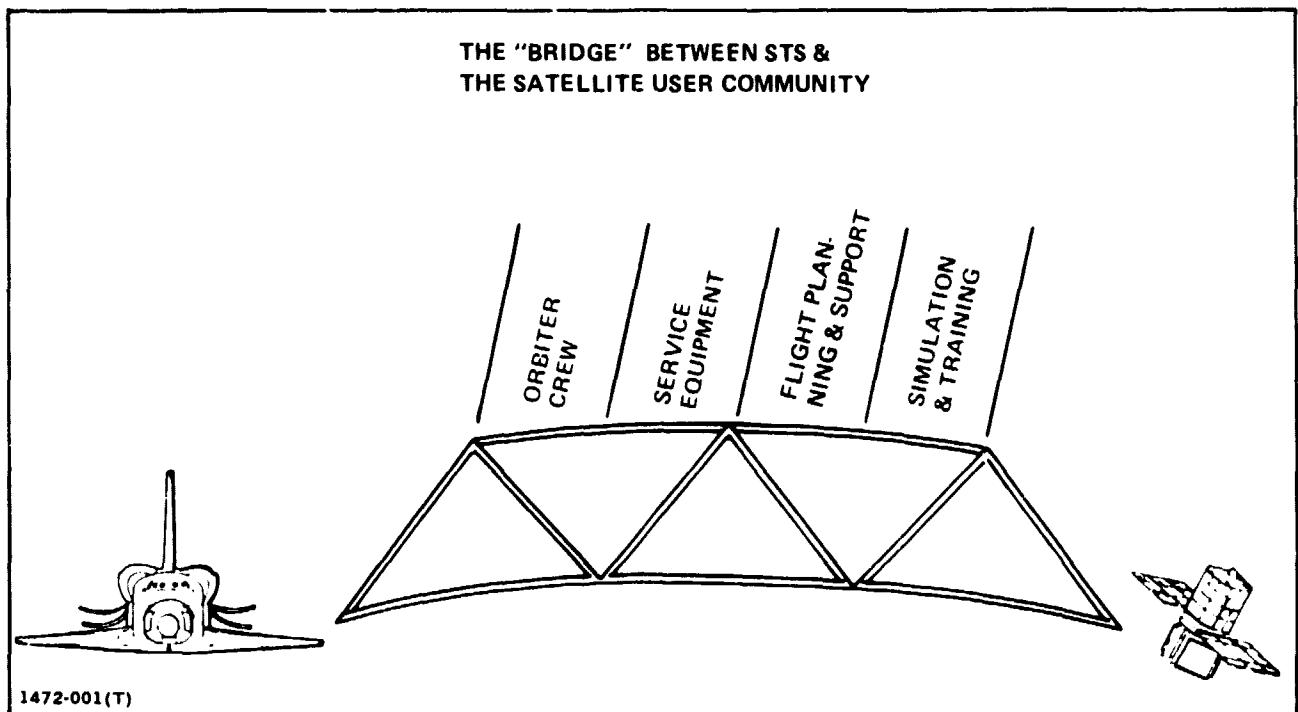


Fig. 1-1 Satellite Services System

2 – Study Objectives and Scope

The overall purpose of this system analysis study was to identify the elements and features of an effective Satellite Services System (SSS) responsive to the near-term and anticipated future needs of the satellite user community. In support of that objective, the study has identified:

- The scope of services potentially needed by the satellite community
- When the servicing capability should be made operationally available
- The types of service equipment and related servicing modes that would be applicable
- The resources and implementation plans needed to bring the Satellite Services System on-line in timely fashion.

Major emphasis has been placed on identifying service needs directly associated with the Orbiter

and within a range of a few kilometers.

Services have been considered for low earth orbit (LEO) satellites and those within a reasonable range for retrieval; services for geosynchronous earth orbit (GEO) satellites were beyond the scope of this effort except for service functions associated with LEO deployment of GEO satellites. Principal attention is directed toward satellites potentially needing services in the time-period of 1983 through 1988 with a lower level of emphasis applied to service needs from 1988 through 1993. Both planned and presently-orbiting satellites, applicable to the respective time periods, have been considered including orbiting elements classified as debris.

An overview of the study approach is shown in Fig. 2-1. The study was structured in two parts, a conceptual analysis effort and a preliminary design/planning activity.

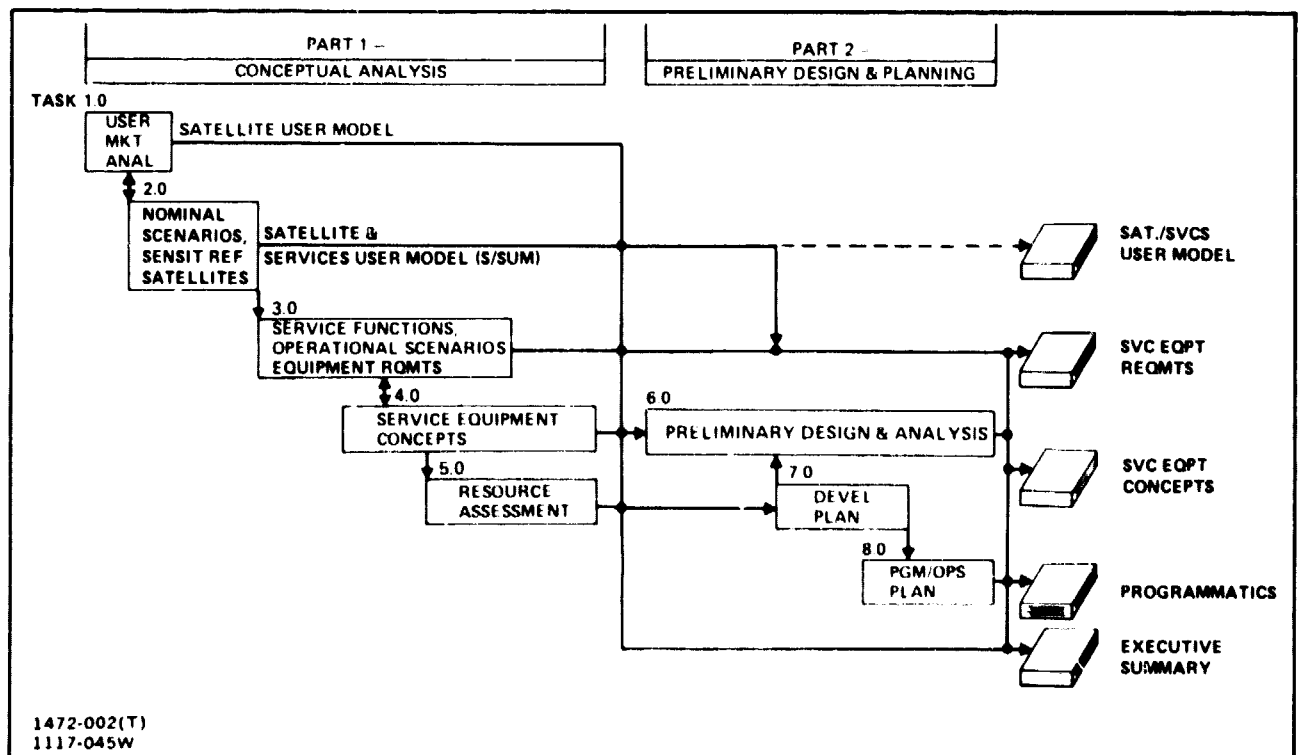


Fig. 2-1 Study Logic & Major Outputs

Part 1 of the study emphasized evaluation of potential service needs and development of viable service system concepts. An initial Satellite User Model was developed to identify candidate satellites, their sponsoring organizations, and their potential service needs. This model was subsequently refined to reflect the influence of the potential service needs in a time-phased (schedule) manner, and an overall Satellite/Services User Model was established to serve as a baseline for the study. From this baseline, design reference satellites were selected to serve as a

framework for developing service system requirements and equipment concepts. The baseline Satellite/Services User Model is also used as the basis for scoping the overall program and resource needs for a total Satellite Services System.

Part 2 of the study addressed further amplification of service equipment designs and the preparation of preliminary development, program/operations plans that are needed to bring on-line and implement a Satellite Services System.

3 – Satellite and Services User Model

During the initial phase of this study, a Satellite User Model was developed to identify potential service needs associated with candidate satellite programs of the future and the frequency of the service events as a function of time. It became apparent, however, that a more meaningful way of grouping service functions/events is in terms of *three mission events*: *initial launch*, *revisit*, and *earth return*. As shown in Fig. 3-1, Initial Launch nominally includes the service functions of checkout and deployment; Revisits include exam, retrieval, checkout, maintenance, resupply, reconfiguration, and deployment; Earth Return involves exam, retrieval, and earth return. Each nominal mission event, therefore, signifies a given number of service functions.

This form of simplification, in terms of mission events, was adopted in the formulation/development of the *Satellite and Services User Model (S/SUM)*. Satellites and payloads in the S/SUM have been grouped according to the satellite classes shown in Fig. 3-2. They include:

- Direct Delivery/Servicing: Satellites capable of direct delivery to orbit and/or servicing by the Orbiter
- LEO/Propulsion: Satellites whose LEO operational altitude is above the Orbiter's nominal delivery orbit

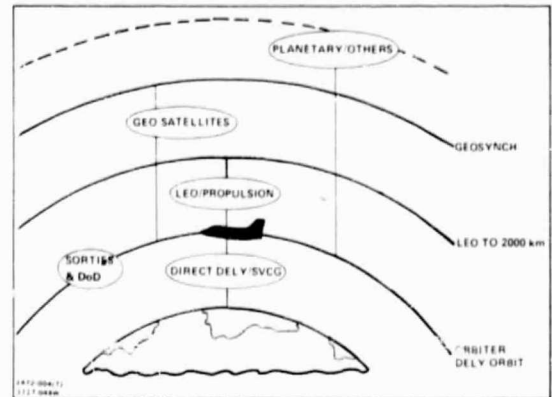


Fig. 3-2 Satellite Classes

- GEO Satellites: Satellites destined for GEO that are deployed in LEO by the Orbiter (except DoD satellites)
- Planetary/Others: Spacecraft destined for planetary missions that are deployed in LEO by the Orbiter. Undefined satellites/payloads which might presently be carried as reflight opportunities in the STS manifest are also grouped herein
- Sorties/DoD: Sortie missions (e.g., Spacelab Flights) and DoD Orbiter flights are grouped herein. To retain the unclassified nature of this study, only publicly-known information relating to DoD flights or payloads is carried in the Satellite and Services User Model.

MAJOR MISSION EVENTS ARE BETTER MEASURES OF SERVICE NEEDS!								
MISSION EVENTS			NOMINAL SERVICE EVENTS					
	DEPLOY	EXAM	RETRIEVAL	EARTH RETURN	CHECK-OUT	MAINT	RE-SUPPLY	RECONFIG
△ INITIAL LAUNCH	•				•			
○ REVISITS	•	•	•		•	•	•	•
▽ EARTH RETURN		•	•	•				

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Fig. 3-1 Mission Events/Service Function Relationships

10

As indicated in Fig. 3-4, the mission events and their related service needs grow to approximately 70 service events in the 1988 time-frame and remain fairly level through the early 1990s. Exclusive of initial launch/deployment, the need for revisit services begins to accelerate in 1986.

Furthermore, in the 1986 to 1990s time period, approximately three times as many launch events are projected as compared to revisit/earth return events. Since present Shuttle manifesting generally accommodates nearly three payloads per Shuttle launch, it would appear that revisit/earth return services could be planned for Orbiter flights after initial launch/deployment of satellite payloads has been accomplished. This would avoid the necessity of scheduling dedicated revisit or earth return missions for other than "special situations."

It is interesting to note, however, that although few satellites/payloads exist (at the moment) in the 1990s phase of the S/SUM, the service need level remains rather high through the 1990s. Clearly, as new satellite programs evolve for that time period, the trend for potential service needs will continue to grow. It would appear, therefore, that our present "stable of satellite candidates" for the 1980s should represent reasonable baselines upon which to develop potential service needs and formulate servicing concepts (including hardware and operations), with a view toward potential standardization.

Additionally, the S/SUM does not reflect the impact of backup/contingency or unscheduled service needs. Our projections, therefore, may be considered as somewhat conservative!

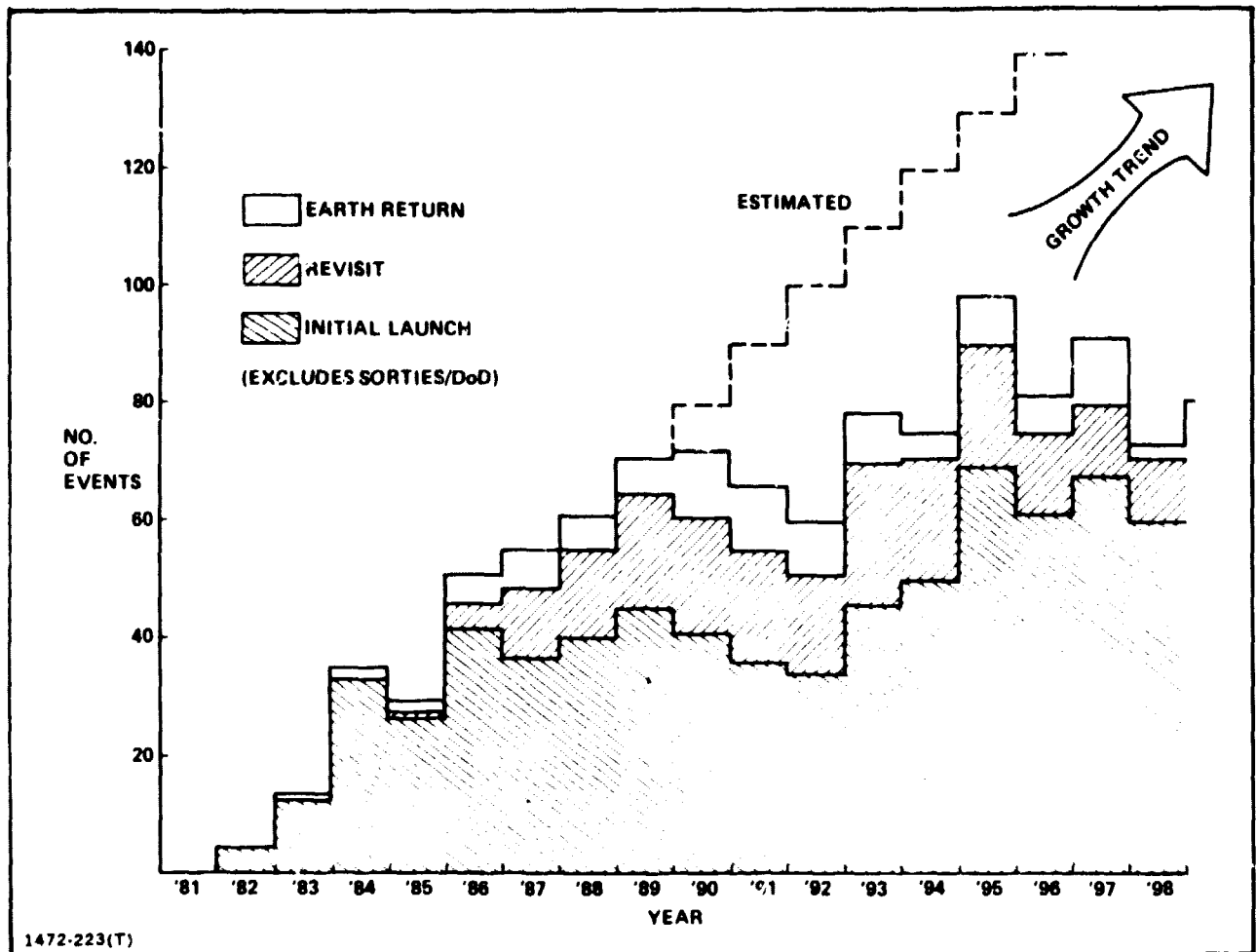


Fig. 3-4 Satellite & Services User Model (S/SUM) – Mission Events

4 – Service Requirements

4.1 Development of On-Orbit Operations Scenarios

The primary technique used in this study to identify service equipment needs/usage was the development of appropriate on-orbit operational scenarios. Servicing scenarios were developed for the three primary mission events: initial launch, revisits, and earth return. As shown in Fig. 4-1, 34 initial launch scenarios, 48 revisit scenarios, and 98 earth return scenarios were considered. The scenarios reflected various satellite classes, nominal and alternate modes of operation, contingency situations (as RMS inoperative), and potential close proximity operations.

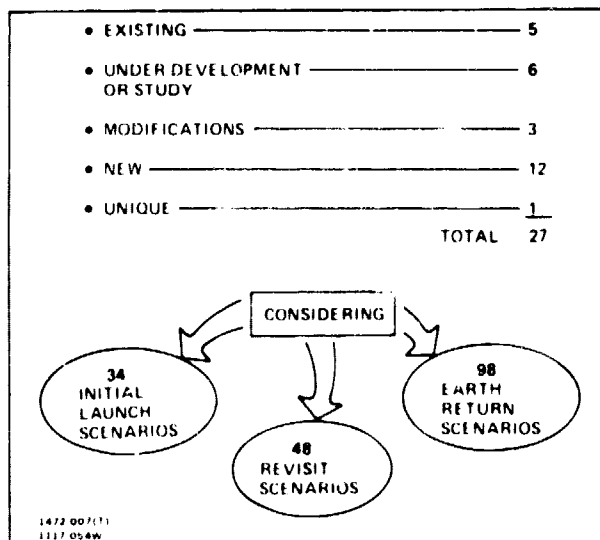


Fig. 4-1 Equipment Identified

Level 1 on-orbit operations scenarios were developed to represent sequences-of-events for more than 20% of the 180 scenarios. The compilation of on-orbit servicing scenarios developed for initial launch, revisits, and earth return missions are found in Volume 3A, Service Equipment Requirements Appendix, of this report. Through this process, 27 items of service equipment were identified as applicable to the servicing scenarios considered in the study.

In developing these on-orbit operations servicing scenarios, the following fundamental goals or objectives were sought:

- Attempt to standardize on-orbit service operations
 - Checkout, servicing, deployment performed from a single Orbiter location
 - Standardize satellite interfaces/checkout approach
- Maximize the use of existing equipment or those under development
- Enhance utilization of the Space Transportation System to the satellite user community
 - Minimize service equipment user charges and cost of on-orbit operations
 - o Multipurpose equipment usage
 - o Minimize on-orbit service time
 - Maximize mission success prospects
 - o Satellites in fully operational condition before deployment
 - o Improved attitude/state vector information
 - o Sun-impingement protection with payload bay doors open
 - o Provide for orbital storage in event of malfunctions.

To accomplish these goals, our approach involved an examination of a broad spectrum of potential servicing scenarios to surface the likely service equipment needs. Within these scenarios are considerations of the following:

- Nominal* /alternate scenarios
- RMS inoperative situations
- Backups for hangup of mechanical devices
- Contamination-sensitive satellites; retrieval/servicing
- Orbiter plume impingement/satellite control implications during close proximity operations.

*Nominal scenarios use existing service equipment as Remote Manipulator System, Flight Support System Tilt Table, PAM-A & PAM-D.

Additionally, the following assumptions were made in developing the on-orbit operations scenarios:

- Status monitoring, checkout, activation/deactivation of satellites is user controlled (satellite communications via Orbiter S-band or satellite's communication system, as appropriate)
- Minimize Orbiter status/checkout involvement
 - Power (as required)
 - Overall health (extent tbd, but standardized for all satellites)
 - Go/No-Go for deployment and servicing verification/effectiveness is satellite user decision
- Satellite deployment is via Orbiter command
- EVA is acceptable service mode
- MTV usage
 - Record LEO/GEO upper stage firings
 - Examine all satellites prior to Orbiter capture/berthing
- Compare RMS/tilt table (FSS cradle A) usage with RMS/Handling and Positioning Aid (HPA) usage for initial launch, revisits, and earth return
- Satellite separation ΔV during deployment imparted by RMS or HPA
- Consider various close proximity operations
 - Orbiter closure
 - "Clean" vehicle closure from 1000 ft separation
 - Versatile Service Stage closure
- All unmanned vehicle closures are controlled by the Orbiter crew
- Orbiter safety considerations
 - Satellite RCS firings - > 200 ft separation
 - Liquid rocket engine firings - > 2700 ft separation
 - Solid rocket engine firings - OMS separation burn required to assure Orbiter exit of hazard envelope
- Uncooperative STS-era satellites assumed capturable via RMS/grapple techniques
 - High tumble rates assumed as "debris situation."

A simplified on-orbit sequence of events for a Revisit mission is shown in Fig. 4-2. This sequence of events represents scenarios where the RMS is used to retrieve satellites and place them on a Handling/Positioning Aid (HPA) for on-orbit servicing. In these scenarios, the HPA becomes

the "standard location" at which servicing and checkout of the satellite is performed, and from which the spacecraft is redeployed from the Orbiter. Retrieval is accomplished by the Orbiter after inspection of the satellite. The service equipment needs associated with a particular event are highlighted in Fig. 4-2. The initial events call for:

- Maneuverable Television (MTV)
- Remote Manipulator System (RMS) and associated Aft Flight Deck Controls/Displays (AFD C&D)
- AFD C&D for close proximity flight control of the MTV.

Subsequent operations identify:

- Handling and Positioning Aid (HPA)
- Work Platform for the HPA
- Open Cherry Picker (OCP) and RMS
- AFD C&D for satellite checkout/servicing support
- Equipment stowage/fluid transfer system for servicing support.

The backup situations identify the following equipment needs:

- Manipulator Foot Restraint (MFR) to cover latch hangups
- HPA work platform (also identified above) to assist a potential satellite appendage hangup.

4.2 Service Equipment Summary

Figure 4-3 summarizes the status and major mission event usage (initial launch, revisits, and earth return) of the service equipment identified within the 180 on-orbit operations scenarios considered in the study. A total of 27 service equipment items could satisfy all equipment needs of the scenarios considered. Of the 27 equipment items identified, their status is as follows:

Existing	6
Under Development or Study	5
Modifications	3
New	12*
Unique	1
Total	27

(*Four optional)

The equipment identified with connecting lines in Fig. 4-3 refers to equipment needs that could be satisfied by single units of service hardware, adapted with appropriate kits to perform the needed service functions. Clearly, many service equipment needs appear on more than one mission event.

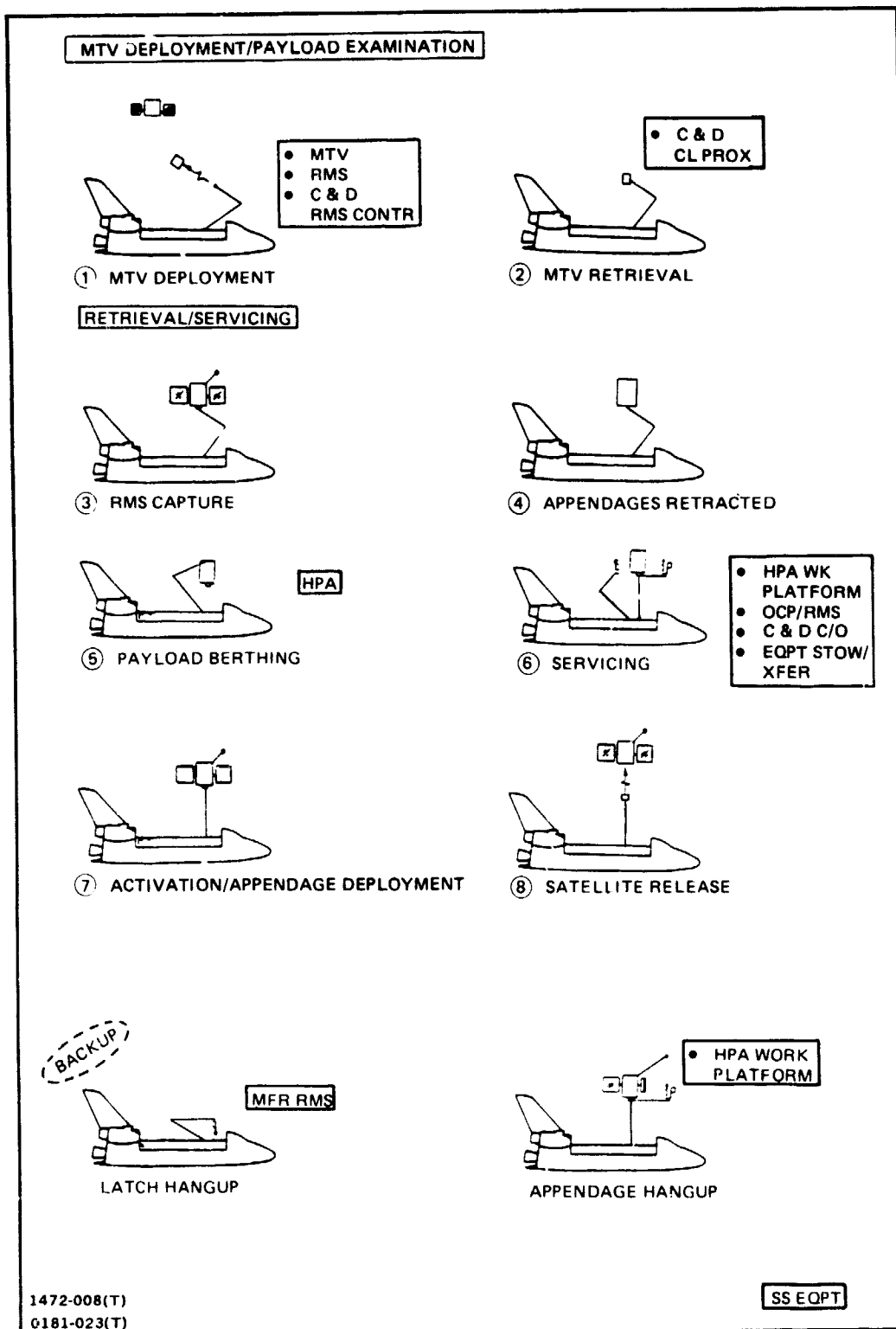


Fig. 4-2 R3 – Alternate No. 1 Revisit Scenario – Direct Delivery Payload Class – Nominal Payload (MMS Class) – RMS/HPA Usage

EQUIPMENT CATEGORY	MISSION EVENT			EQUIPMENT STATUS				
	INITIAL LAUNCH	REVISIT	EARTH RETURN	EXISTS	UNDER DEV OR STUDY	MODIF	NEW	UNIQUE
SUPPORT STRUCTURE								
• RETENTION STRUCTURES	•		•	•				
• SPECIAL RETENTION STRUCTURE			•					•
ON ORBIT EQUIPMENT								
• EQUIPMENT STORAGE		•	•				•	•
ON-ORBIT SUPPORT EARTH RETURN								
• TILT TABLE	•	•	•	•				
• OCP		•	•		•		•	
TILT TABLE WORK PLATFORM OCP/RMS								
• MFR/RMS	○	○	○		•			
• PIDA	•		•		•			
• REMOTE MANIPULATOR SYSTEM (RMS)	•	•	•	•				
• SPIN TABLE (PAM A, PAM D)	•			•				
• HANDLING & POSITIONING AID (HPA)	•	•	•		•			
• FLUID TRANSFER SYSTEM		•					•	
• NON CONTAMINATING ACS		•	•				•	
• AFD CONTR/DISPL	•	•	•	•		•	•	
W/RMS CONTROL W/STD SAT. C/O W/CLOSE PROX CONTR								
FREE FLIGHT SYSTEMS								
• MMU/WRU	○	○	○	• (MMU)		•		
W/END EFFECTOR W/STABILIZER W/PAYLOAD HANDLING PROX OPS MODULE								
• PROX OPS MODULE - MANNED VERSION		•	•				•	
• PROX OPS MODULE MTV ADAPTATION		•	•				•	
• MTV	•	•	•		•			
• (VSS)	•	•	•		•			
W/DELIVERY, RETRIEVAL RENDEZ, DOCKING W/END EFFECTOR KIT W/DEBRIS CAPTURE KIT								
OPTIONAL EQUIPMENT								
• SUN SHIELD	•						•	
• ORBITAL STORAGE	•	•					•	
• ATTITUDE TRANSFER PKG	•	•					•	
• LIGHTING ENHANCEMENT	•	•	•				•	
ADVANCED CAPABILITIES								
• DEXTEROUS MANIPULATORS	•	•	•				•	
W/RMS W/HPA								
TOOLS								
• HANDLING EQUIPMENT REMOVAL		•	•		•			
MISSION EVENT CODE PRIME USAGE • BACKUP ○								
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Fig. 4-3 Service Equipment Summary

4.3 Crew Interaction

Orbiter crew interactions involve remote control functions from the AFD and performance/control of service operations during EVA. Specific crew involvements are:

- *Control of Service Equipment Operations* such as those associated with the RMS, HPA FSS Tilt Table, and Retention Structure Latches
- *Close Proximity Flight Control* of the MTV, Proximity Operations Module - MTV Adaptation, and Versatile Service Stage
- *Satellite Activation and Checkout* which could involve providing power to the satellite, transferring attitude and state vector information, and a minimal (yet to be standardized) checkout of status/health prior to deployment.

Crew Extra-vehicular activities involve:

- *Control of Service Equipment Operations* within the payload bay, such as those associated with the operation of the OCP/RMS, OCP work stations on the FSS Tilt Table and HPA, and support of RMS equipment removal and stowage operations
- *Free-flight Operations Involving Close Proximity Satellite Retrieval* such as those associated with retrieval operations using the Proximity Operations Module - MMU/WRU adaptation
- *Hands-on Repair/Maintenance* including module exchange and potential fluids replenishment
- *Contingency Situations* with the RMS inoperative or involving mechanism hangups which would call for deployment of the MFR/RMS or appropriate MMU/WRU adaptations.

These crew interactions indicate that on-orbit crew involvement is an inherent part of satellite services in primary (as well as contingency) service operations.

4.4 Satellite Features Facilitating Servicing

Salient satellite features which would enhance serviceability of satellites by the Orbiter/Orbiter

Crew are:

- A standardized interface should be established between all satellites and the Orbiter which would contain berthing, umbilical, and fluid transfer connections compatible with the HPA and FSS Cradle A' Tilt Table
- The extent of Orbiter crew involvement in satellite checkout operations should be standardized and, to the extent possible, minimized to reduce control/display implications on the Orbiter
- Satellite appendages should be deployable while attached to the Orbiter to take advantage of the crew's presence for backup. Appendages should also be retractable to allow servicing flexibility, access to equipment, and storage for earth return
- An RMS grapple fixture(s) should be located on the satellite to be compatible with planned servicing operations
- Satellite safing should be incorporated in all satellites that require retrieval for servicing or subsequent earth return (e.g., expel residual propellants prior to retrieval).

Satellites intended for on-orbit maintenance should be designed with basically the same type of ground rules applied to all man-tended systems, with particular attention paid to man-tended EVA compatibility. Five basic ground rules that apply to on-orbit servicing of satellites are:

- Accessibility
 - EVA Servicing - Reach/Visibility Requirements
 - Mobile Foot Restraint/OCP Positioning Capabilities
- Module Size/Form Factors Compatible with EVA Handling
- Removal and Replacement Simplicity
 - Minimize Equipment Mounting Points
 - Mechanical Retention Mechanisms
 - Umbilical Connectors
 - Visual Verification of Connection Acceptability
- Module Transportability via EVA and/or RMS
- Standardized On-Orbit Tool Usage

5 – Service Equipment Concepts

The service equipment identified in Section 4.2 can be conveniently grouped within the following satellite service operations:

- Payload Deployment
- Close Proximity Retrieval
- On-Orbit Servicing
- Backup/Contingency
- Delivery/Retrieval of High Energy Payloads (LEO/Propulsion Class)
- Earth Return
- Optional Services/Advanced Capabilities.

Subsequent sections of this report illustrate the service equipment concepts/usage applicable to these service operations.

5.1 Payload Deployment Equipment

Satellite service equipment associated with payload deployment operations includes:

- Retention Structures
- Remote Manipulator System (RMS)*
- Tilt Table*
- Payload Installation/Deployment Aid (PIDA)*
- Handling and Positioning Aid (HPA)
- Spin Table*
- Aft Flight Deck Controls and Displays (AFD C&D).

Equipment noted with an asterisk (*) is described and illustrated in this subsection.

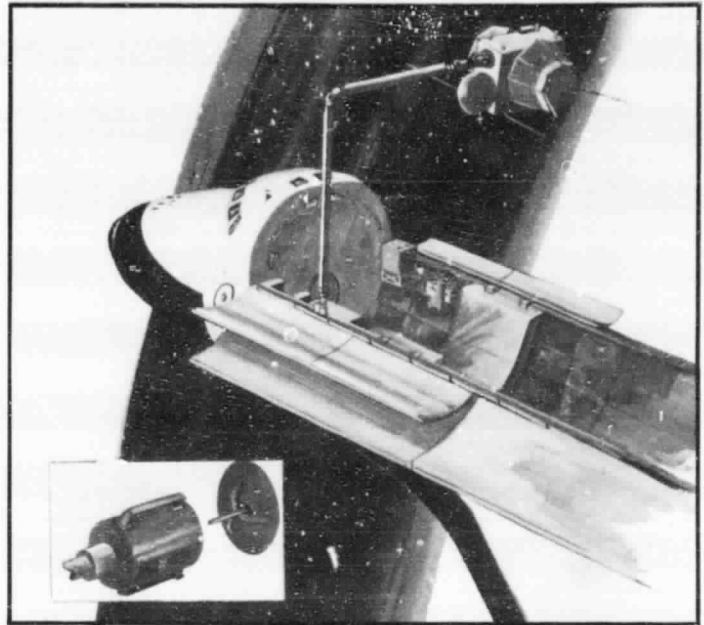


Fig. 5-1 Deployment Retrieval – Remote Manipulator System

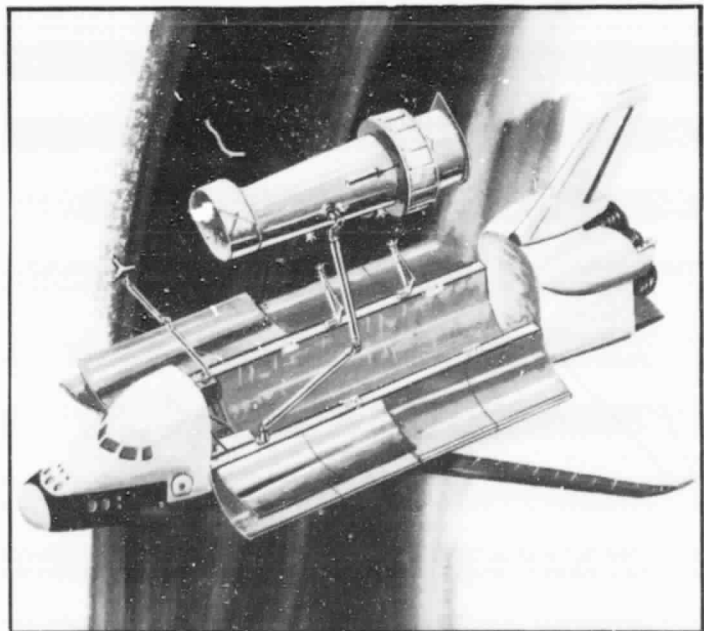


Fig. 5-2 Deployment – Payload Installation & Deployment Aid

FOLDOUT FRAME

Remote Manipulator System

The Remote Manipulator System (RMS) can be used to deploy payloads from the Orbiter payload bay. Of particular note to the satellite user are the standard RMS elements: the snare end effector and its compatible grapple fixture (see Fig. 5-1). These elements have been designed to release a satellite with essentially no differential velocity during deployment. Nominal capabilities of the RMS are:

- Payload Handling Capability: 65,000 lb
- Positioning Accuracy: 2 in. \pm 1 deg within reach envelope
- Payload Release: \pm 5 deg attitude < 0.015 deg/sec relative.

The RMS is also used to retrieve satellites, when they are within the reach distance of the RMS arm, to enable on-orbit servicing or earth return.

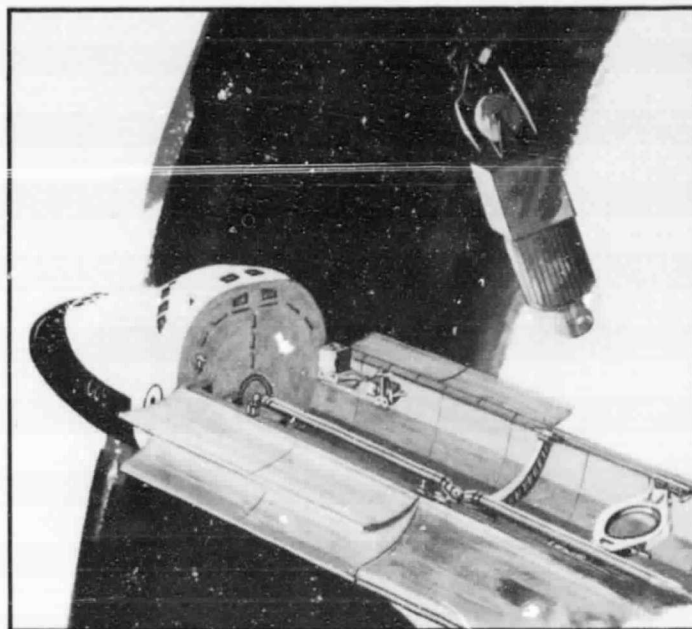


Fig. 5-3 Deployment — Inertial Upper Stage

Payload Installation and Deployment Aid

The Payload Installation and Deployment Aid (PIDA) is a mechanism which enables deployment (and reinstallation) from the payload bay of very large size/mass payloads (e.g., 15 ft diameter and 65,000 lb). The device, which is currently under development at the NASA Johnson Space Center, provides automatic deployment and stowing of satellites having minimum clearance envelopes with the Orbiter payload bay. Figure 5-2 shows the PIDA having lifted a large satellite out of the payload bay and transferred it to the RMS, to enable its subsequent checkout and deployment from the Orbiter.

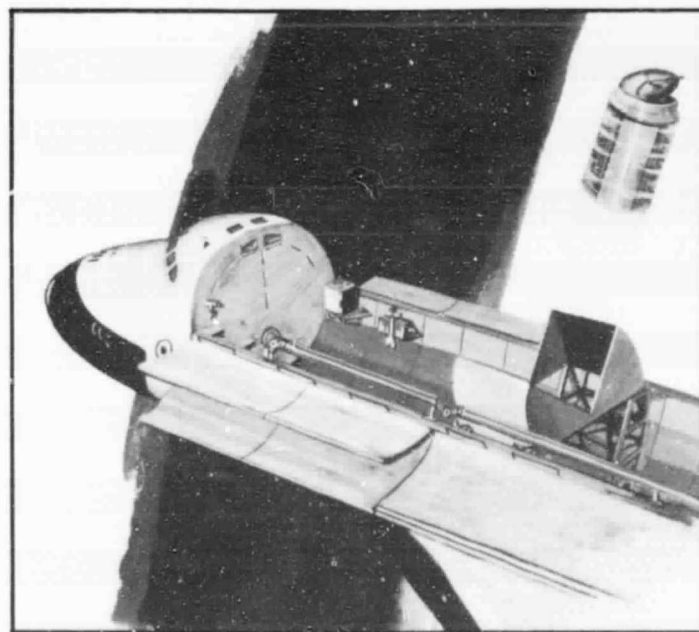


Fig. 5-4 Deployment — Spinning Upper Stage



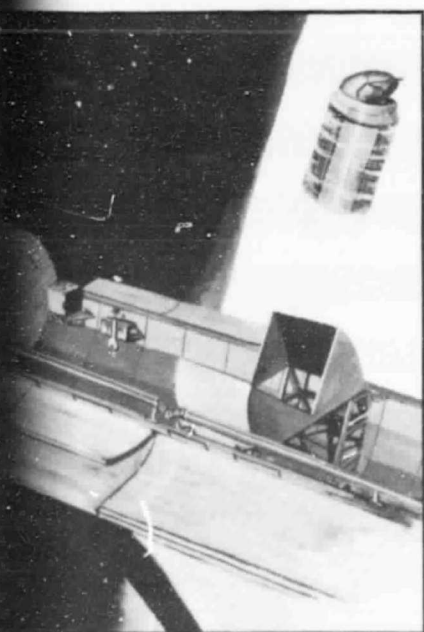
ment - Inertial Upper Stage

Inertial Upper Stage

The solid propellant, 3-axis stabilized Inertial Upper Stage (IUS) is designed to boost spacecraft to higher energy orbits. The performance design requirement for the two-stage IUS to a geostationary orbit is 5000 lb.

The IUS comes with forward and aft retention frames to support the satellite/IUS in the Orbiter payload bay. Included with the aft frame is a Tilt Table to raise the satellite/IUS out of the payload bay; the Tilt Table also incorporates a stored energy release system for IUS separation from the Orbiter.

Following deployment (see Fig. 5-3), the satellite/IUS drifts to a separation distance of 200 ft and the IUS Reaction Control System is activated. A minimum separation distance of 80 mi is necessary before activating the IUS stage to protect the Orbiter from contamination by the solid propellant effluents. The Orbiter performs a separation maneuver to provide this separation distance within 45 min of deployment.



ment - Spinning Upper Stage

Spinning Upper Stage

The solid propellant, spinning upper stage is designed to launch spacecraft into geostationary transfer orbits. Two types of stages called Payload Assist Modules (PAM) are being developed: the PAM-A and PAM-D. Injection weights for these stages are 4400 lb and 2750 lb, respectively. PAM-D (shown in Fig. 5-4) includes a cradle support structure, a spin system, a separation mechanism to deploy the payload, and a sun shield for thermal protection with the Orbiter payload bay doors open.

Following payload deployment, the Orbiter performs a maneuver to provide a safe separation distance and protect against contamination by the solid propellant effluents. This separation maneuver is performed within 45 min of deployment.

RELEASE FRAME

3

5.2 Close Proximity Retrieval Equipment

Satellite service equipment associated with close proximity retrieval operations includes:

- Remote Manipulator System (RMS)
- Maneuverable Television (MTV)*
- Proximity Operations Modules*
 - MTV Adaptation
 - Manned Maneuvering Unit/Work Restraint Unit (MMU/WRU) Adaptation
- Aft Flight Deck Controls/Displays (AFD C&D).

Equipment noted with an asterisk (*) is described and illustrated in this subsection.

Maneuverable Television

A Maneuverable Television (MTV) is shown (see Fig. 5-5) being deployed from the Orbiter by the RMS. The MTV is a free-flying spacecraft, remotely flown by the Orbiter crew from the Aft Flight Deck, with video and telemetry transmission back to the Orbiter.

The MTV has a range of about three miles and is used to remotely examine all satellites prior to Orbiter retrieval. It can also be deployed to view and record propulsion stage firings of satellites destined for higher energy LEO altitudes or geostationary orbit. Following its examination mission, the MTV is flown back to the Orbiter and retrieved by the RMS.

Also shown in Fig. 5-5, in retracted position, is the Handling and Positioning Aid which will be deployed over-the-side to provide a fixed platform for spacecraft servicing aboard the Orbiter.

The MTV is shown (see Fig. 5-6) examining a spacecraft prior to retrieval for servicing. This free-flying spacecraft is remotely flown by the Orbiter crew from the Aft Flight Deck (AFD).

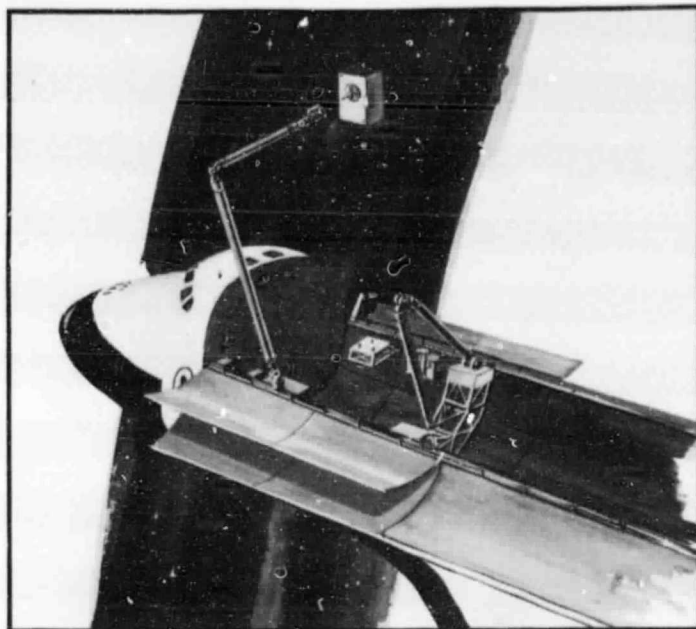


Fig. 5-5 Maneuverable Television Deployment

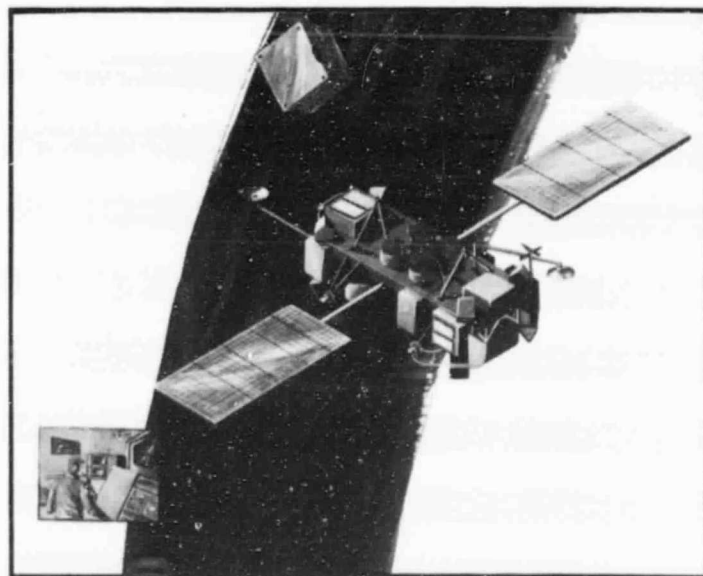


Fig. 5-6 Satellite Examination via MTV

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Unmanned Proximity Operations Module – Satellite Capture/Retrieval

The Orbiter can readily rendezvous with a satellite to within 1000 ft separation distance. However, concerns by some satellite users regarding Orbiter thruster plume impingement or contamination during terminal closure maneuvers could preclude direct Orbiter rendezvous/retrieval of a spacecraft. Retrieval of satellites within a 1000 ft range can be accomplished by an adaptation of the MTV, the Unmanned Proximity Operations Module (POM).

Controlled by the Orbiter crew, the POM would be dispatched to capture the satellite and return it to within reach distance of the RMS. It would be flown via TV (essentially using MTV equipment) and capture its target via the satellite's RMS-compatible grapple fixture. The POM utilizes a non-contaminating, cold gas propulsion system which provides three axes of control during free flight and satellite towing operations. Figure 5-7 shows the unmanned POM, equipped with an extendable mast and RMS end-effector, as it is about to capture a satellite.

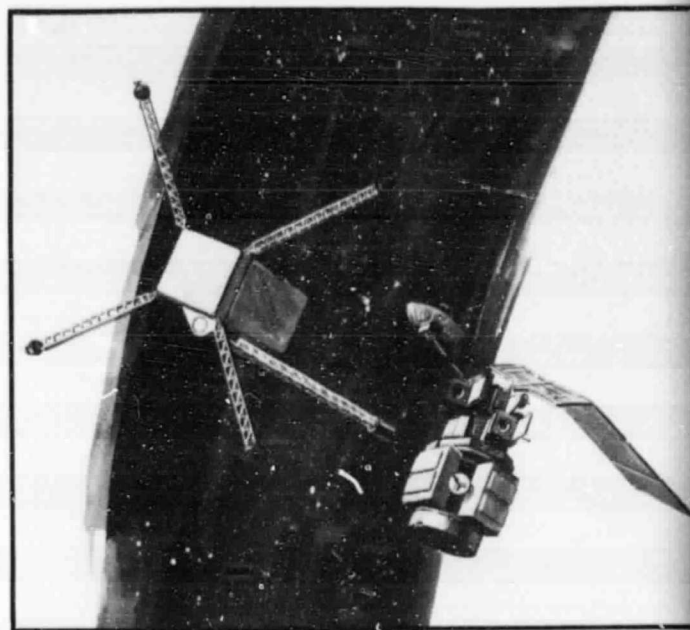


Fig. 5-7 Unmanned Proximity Operations Module – Satellite Capture

Figure 5-8 shows an unmanned POM towing a satellite to the Orbiter. The POM would stabilize/position the satellite within reach distance of the RMS arm and then detach itself from the satellite's grapple fitting to allow the RMS to capture the satellite. Following capture, the RMS would place the satellite on a Tilt Table or HPA to enable on-orbit servicing.

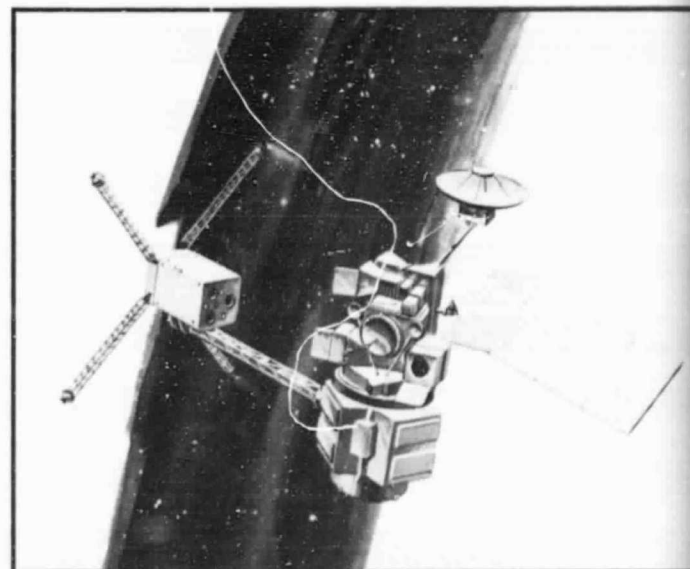


Fig. 5-8 Unmanned Proximity Operations Module – Satellite Retrieval

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Manned Proximity Operations Module – Satellite Capture/Retrieval

Retrieval of satellites within a 1000 ft separation distance of the Orbiter can also be accomplished by a manned Proximity Operations Module (POM). The manned POM is an adaptation of the WRU and can be used in conjunction with an MMU to retrieve moderate-sized satellites of the Multimission Modular Spacecraft class.

The WRU is equipped with an extendable mast and an RMS end effector which are mounted to a support structure. This enables the astronaut to fly with the snare end effector in a forward position during satellite engagement and in an aft position during satellite towing operations. An astronaut would fly the manned POM to the satellite, capture it via the satellite's RMS-compatible grapple fixture, and tow the satellite to within reach distance of the RMS. Figure 5-9 shows the manned POM "flying-in" the end effector to engage the satellite's grapple fixture. As most of the major hardware elements for this concept exist or are in late stages of development, the manned POM is a conceivable choice for near-term satellite retrieval missions.

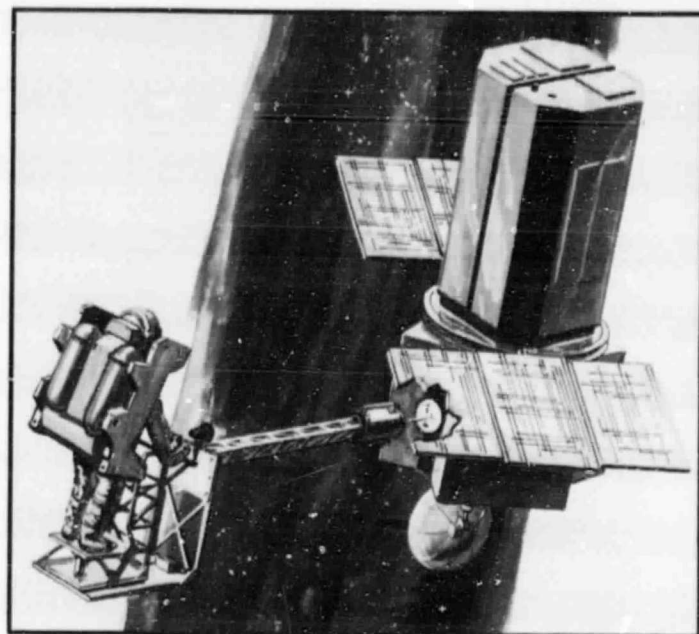


Fig. 5-9 Manned Proximity Operations Module – Satellite Capture

Figure 5-10 shows a manned POM towing a spacecraft to the Orbiter. Using the flight control capabilities of the MMU, the astronaut would stabilize/position the satellite within reach distance of the Orbiter RMS arm. The POM would then detach itself from the satellite's grapple fixture to allow the RMS to capture the satellite. Following capture, the RMS would place the satellite on a Tilt Table or HPA for on-orbit servicing.

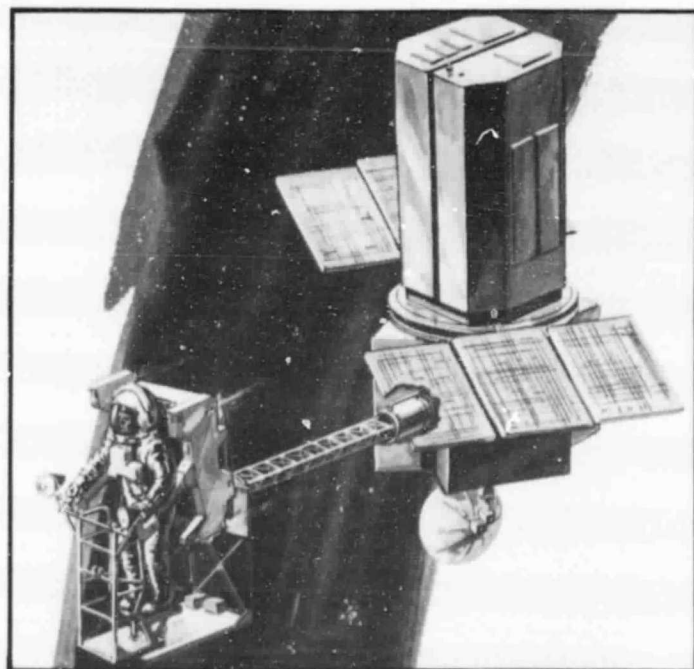


Fig. 5-10 Manned Proximity Operations Module – Satellite Retrieval

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5.3 On-Orbit Servicing Equipment

Satellite service equipment associated with on-orbit servicing operations includes:

- Open Cherry Picker/Remote Manipulator System (OCP/RMS)*
- Tilt Table/OCP Work Platform*
- Handling and Positioning Aid (HPA)*
- Equipment Storage
- Fluid Transfer*
- Non-Contaminating Attitude Control System (ACS)*
- Aft Flight Deck Controls/Displays (AFD C&D).

Equipment noted with an asterisk (*) is described and illustrated in this subsection.

Open Cherry Picker Servicing

The Open Cherry Picker (OCP) is a movable work station controlled by an astronaut on the tip of the RMS arm. Servicing capabilities include lighting, tool storage, a payload handling and transport device, and a stabilizer to rigidly position the astronaut at the work site.

Figure 5-11 depicts an astronaut replacing an equipment module on a representative Multimission Modular Spacecraft. The OCP, with its movable foot restraint, reduces the physical effort associated with performing EVA and, with its control station, allows the astronaut to fly himself into the most convenient position to perform service functions within the Orbiter Payload bay.

Open Cherry Picker - FSS Work Platform Servicing

An OCP can be adapted to the FSS Cradle A' Tilt Table, (as shown in Fig. 5-12), to provide a convenient work platform for spacecraft servicing. The work platform can be positioned at varying distances from the satellite and, with the 360° rotational feature of the Tilt Table, provide total access to all satellite locations.

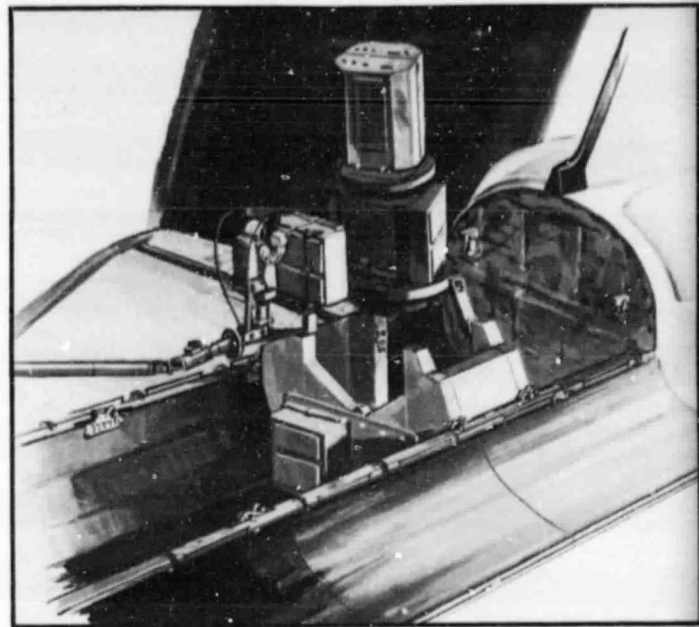


Fig. 5-11 Open Cherry Picker Servicing

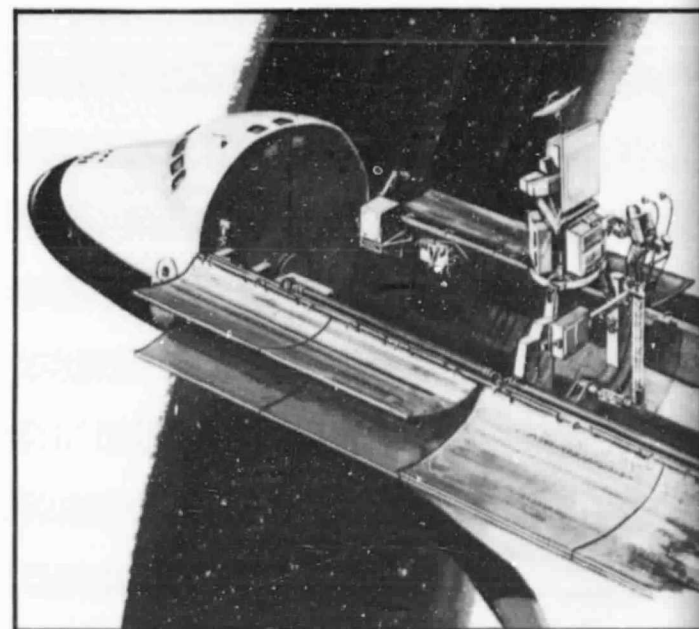


Fig. 5-12 Open Cherry Picker - FSS Work Platform Servicing

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GOLDEN STATE



S Work

Handling and Positioning Aid

The Handling and Positioning Aid (HPA) will support satellites outside the confines of the payload bay and, with its "over-the-side" feature, could enable full deployment of satellite appendages (if desired) prior to release from the Orbiter (see Fig. 5-13). For initial launch missions, the HPA contains a standardized berthing and umbilical interface for checkout prior to deployment, has provisions for transferring attitude/state vector information to the satellite from the Orbiter navigation system, and provides the means to impart a separation velocity between the satellite and Orbiter during deployment. A spin table capability can also be accommodated.

On-orbit servicing is accommodated by rotating turn-table provisions in the HPA and via a movable work platform incorporating an OCP. The work platform has translational and vertical motion capability which, with the HPA turn-table features, enables total access to all satellite locations. The standardized berthing and umbilical interface also contains a fluid coupling interface to transfer propellants during servicing missions.



S Work

Dual Servicing Capabilities

Figure 5-14 depicts a two-astronaut servicing capability. One astronaut is shown servicing a segment of the satellite via the OCP mounted to the end of the RMS arm. The second astronaut utilizes the OCP work platform on the Handling and Positioning Aid.

Although not shown in the illustration, the OCP with its stabilizer feature could attach itself to the satellite, release from the RMS, and enable the RMS to transport equipment from the Orbiter payload bay to the respective work stations.

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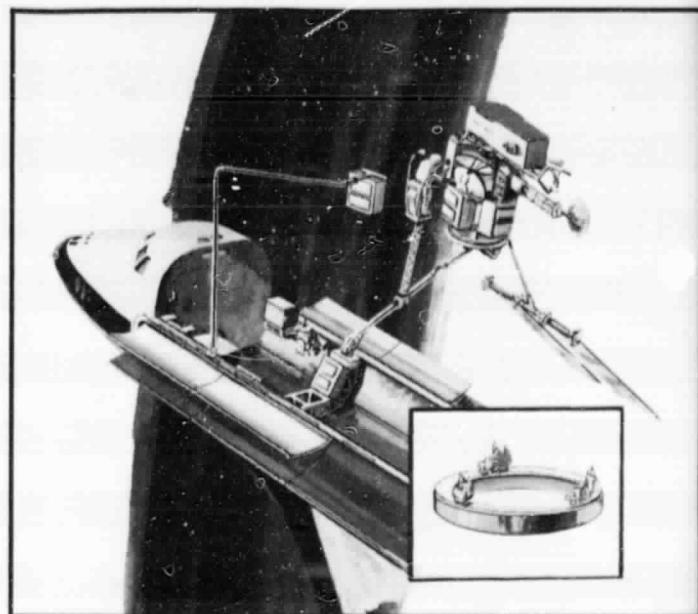


Fig. 5-13 Servicing via Handling & Positioning Aid

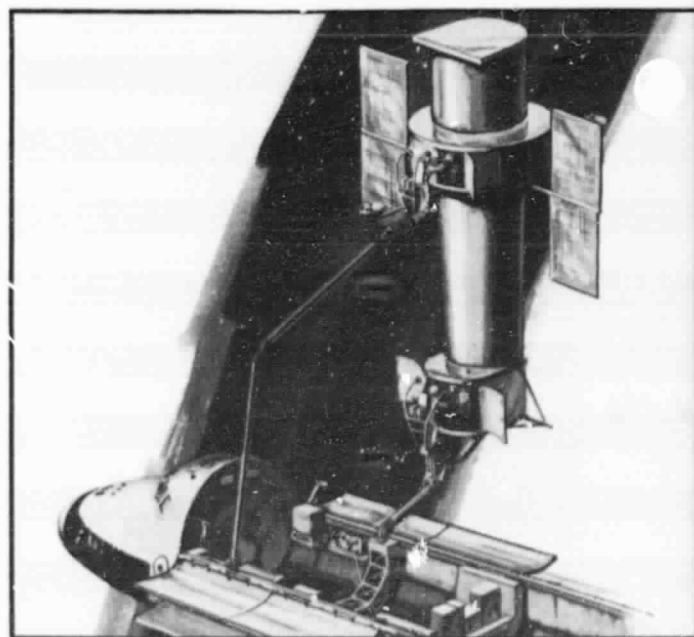


Fig. 5-14 Dual Servicing Capabilities

Fluid Transfer

Provisions are needed for storage and transfer of propellants for satellites and the Versatile Service Stage (VSS). Fluids replenishment could involve both direct tankage/fluid replacement and transfer of propellants via a special fluid transfer system. Either approach, however, is dependent on more detailed definitions of satellite(s) and propulsion stage requirements than are presently available.

Figure 5-15 depicts a fluid transfer module in the payload bay replenishing propellant for a VSS through an interface connection in the HPA.

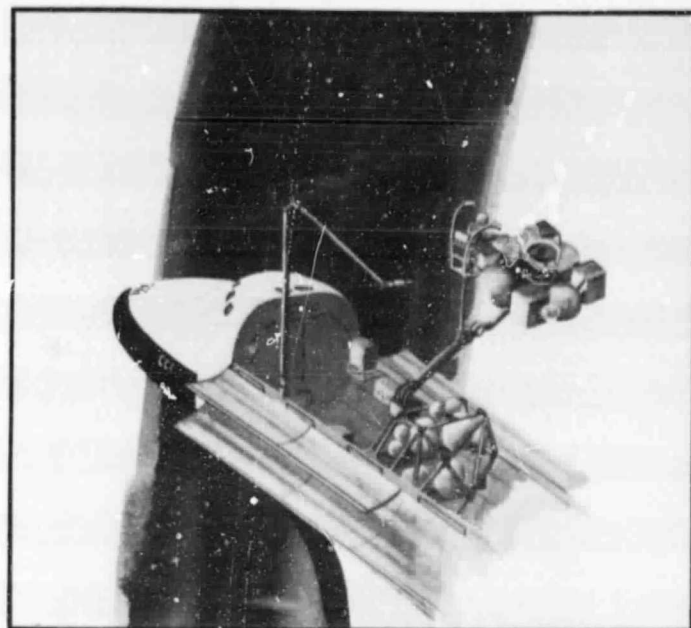


Fig. 5-15 Fluid Transfer

Non-Contaminating Attitude Control System - Servicing of Contamination-Sensitive Satellites

Orbiter servicing of contamination-sensitive satellites can be accomplished by providing a non-contaminating ACS package in the payload bay. The package would provide precision, long-term attitude control without the use of the Orbiter's primary or vernier reaction control systems. Alternatively, and if acceptable, the Orbiter could be placed into a free drift mode.

Figure 5-16 shows a non-contaminating ACS concept consisting of Skylab-type CMGs located in the payload bay, with cold gas thrusters/ N_2 propellant mounted on extensible arms to serve as momentum unloading devices.

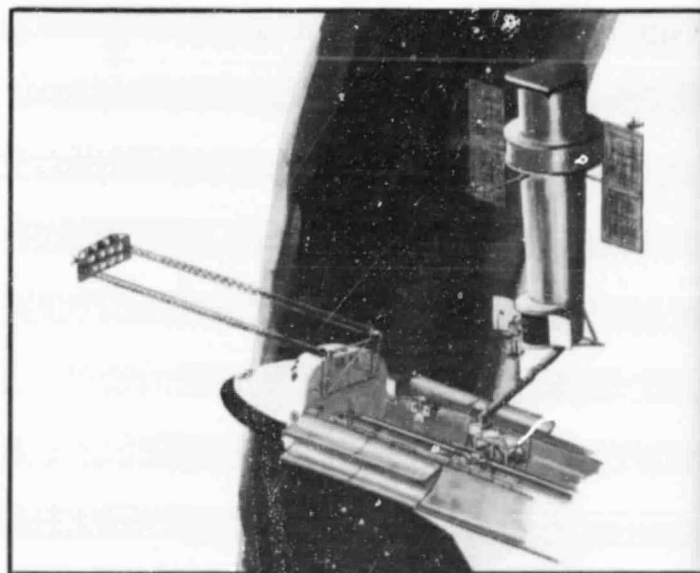


Fig. 5-16 Non-Contaminating ACS - Servicing of Contamination Sensitive Satellites

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5.4 Backup/Contingency Equipment

Satellite service equipment associated with backup/contingency operation includes:

- Manipulator Foot Restraint/Remote Manipulator System (MFR/RMS)*
- Manned Maneuvering Unit/Work Restraint Unit (MMU/WRU) adaptations*
 - End Effector for Satellite Deployment
 - Stabilizer for Mechanical Hangup Situations
 - Payload Handling for On-Orbit Servicing Support

Equipment noted with an asterisk (*) is described and illustrated in this subsection

Manipulator Foot Restraint - Backup for Mechanical Hangups

The Manipulator Foot Restraint (MFR) is mounted on the end of the RMS arm and used to support contingency operations in the payload bay which require EVA. The MFR/RMS serves as a backup for potential hangup of retention latches, mechanical hangup situations associated with satellite appendage deployment, and EVA support of sortie missions.

Figure 5-17 shows an astronaut being deployed on the MFR to manually release a retention latch. In addition to providing the astronaut with a foot restraint which reduces physical effort required to perform EVA tasks, the MFR includes a tool bin to carry supporting tools that may be needed for backup operations.

Work Restraint Unit - Backup for Mechanical Hangups

If the RMS is inoperative or malfunctioning on a satellite deployment mission, an adaptation of the WRU, in conjunction with an MMU, would serve as a backup for hangups of spacecraft retention latches. The WRU is adapted with a stabilizer to rigidly position the astronaut to a work site. Figure 5-18 shows an astronaut within the MMU/WRU with the stabilizer attached to hand rails along the payload bay. The astronaut is preparing to manually release a payload retention latch.

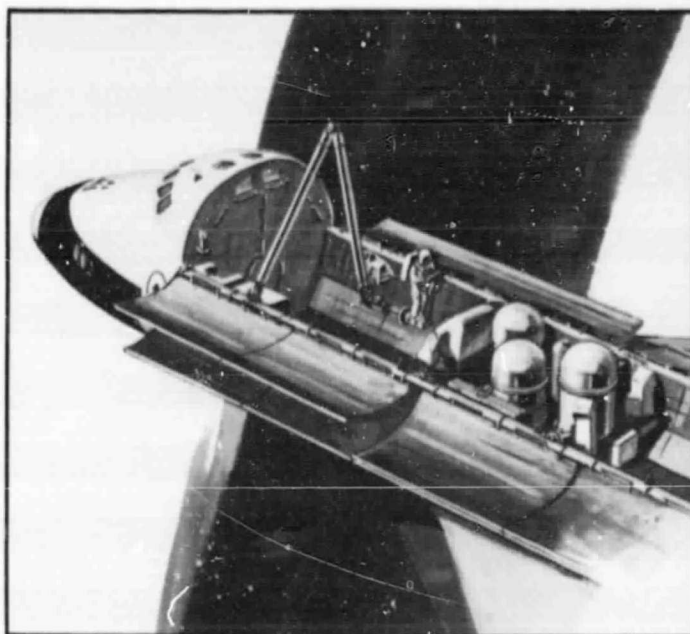


Fig. 5-17 Manipulator Foot Restraint - Backup for Mechanical Hangups

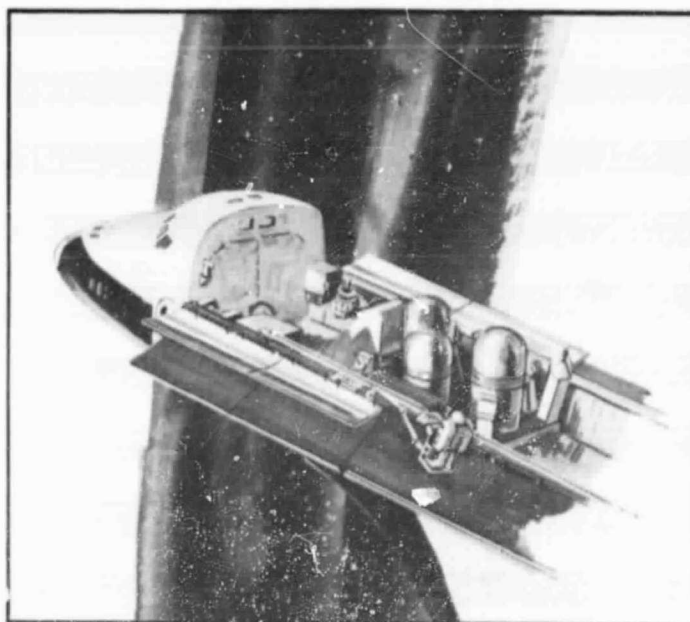


Fig. 5-18 Work Restraint Unit - Backup for Mechanical Hangups

Work Restraint Unit - Backup for Satellite Deployment

An adaptation of a WRU, used in conjunction with an MMU, serves as a backup for satellite deployment in the event that the RMS is inoperative or malfunctioning. The WRU is adapted with an extensible mast and an RMS snare end effector that is compatible with the satellite's grapple fixture used for deployment. Figure 5-19 shows an astronaut within the MMU/WRU (having "flown" and attached to the satellite's grapple fixture) who is preparing to withdraw the spacecraft from the Orbiter payload bay. This adaptation of the WRU is identical to the Manned Proximity Operations Module presented in Section 5.2.

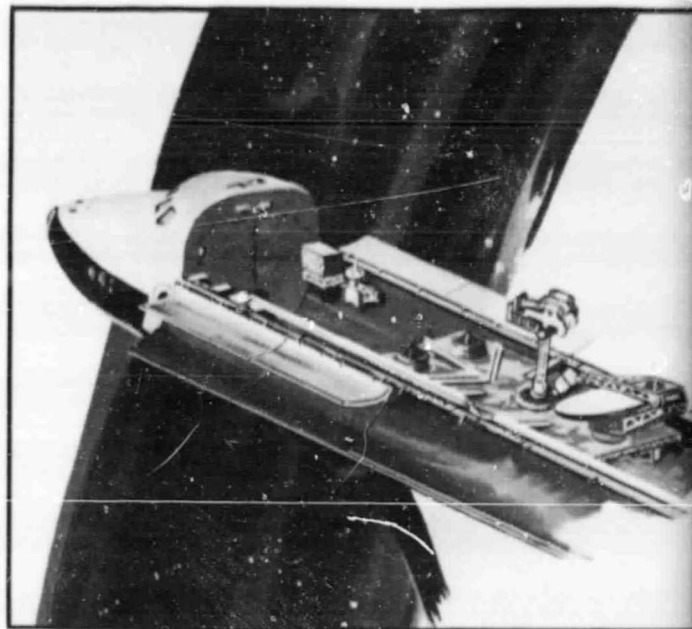


Fig. 5-19 Work Restraint Unit - Backup for Satellite Deployment

Figure 5-20 shows an astronaut within the MMU/WRU "flying" the satellite out of the payload bay. The astronaut would then orient the satellite for deployment and, with the MMU's propulsion system, impart a separation velocity of about 1 ft/sec to the satellite.

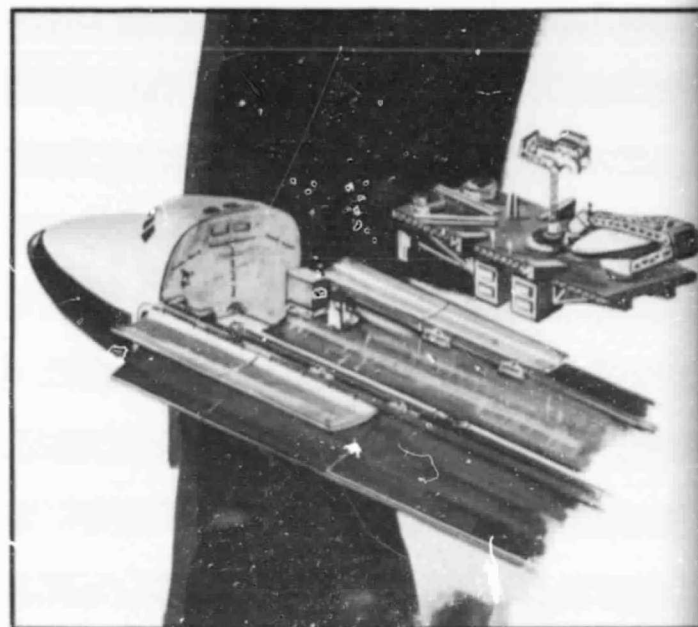


Fig. 5-20 Work Restraint Unit - Backup for Satellite Deployment

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Work Restraint Unit - Backup for Satellite Appendage Hangups

An adaptation of the WRU, in conjunction with an MMU, also serves as a backup for hangups of spacecraft appendages that might occur during deployment of satellites by the RMS. The WRU is adapted with a stabilizer that rigidly positions an astronaut to a work site enabling him to intercede in a mechanical hangup situation. Figure 5-21 shows an astronaut within the MMU/WRU with the stabilizer attached to a "hard point" on a satellite. The astronaut is preparing to manually release a solar array mechanism. The WRU stabilizer adaptation, therefore, is applicable for both RMS operative and inoperative situations.

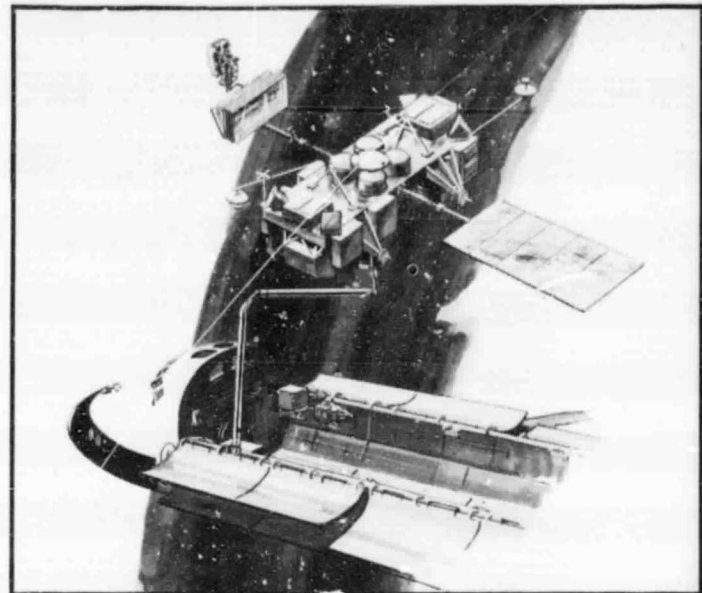


Fig. 5-21 Work Restraint Unit - Backup for Satellite Appendage Deployment

Work Restraint Unit - Backup for Servicing Support

A revisit service mission could also be performed with the RMS inoperative with appropriate adaptations of the WRU. A WRU adapted with an RMS snare end effector could retrieve payloads within the local vicinity of the Orbiter and position the payloads on a Tilt Table or HPA for on-orbit servicing. Further, a payload handling adaptation of the WRU could transport replacement equipment/modules from the payload bay to the work platform at the service site. Figure 5-22 shows an astronaut using the MMU/WRU to transport an equipment module to a second astronaut who is servicing a satellite mounted on the HPA.

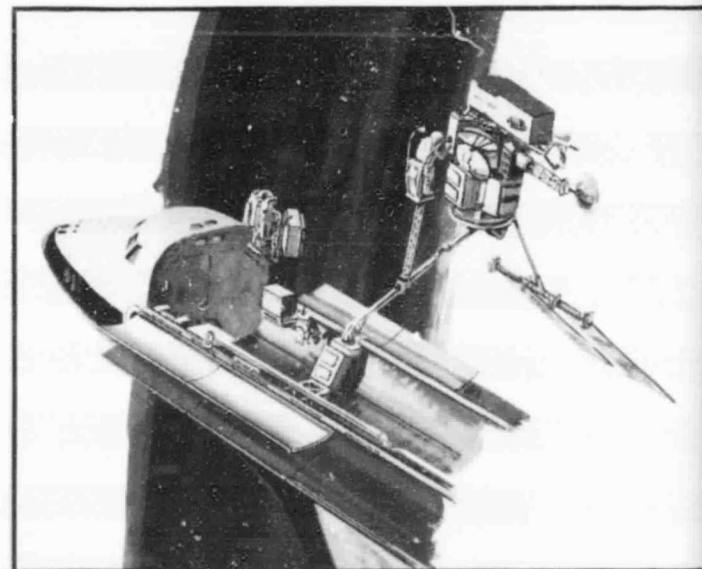


Fig. 5-22 Work Restraint Unit - Backup for Servicing Support

The three illustrated adaptations of the WRU (RMS snare end effector, payload handling, and stabilizer) are implemented in terms of "kits" that are adaptable to a single WRU carried on the service mission.

5.5 Delivery/Retrieval of High Energy Payloads

Satellite service equipment associated with delivery and retrieval of LEO/Propulsion class payloads includes:

- Versatile Service Stage (VSS)*
 - Delivery, Rendezvous, Docking, and Retrieval Capability
 - End Effector Kit for Non-Cooperative Satellite Stabilization
- Aft Flight Deck Controls/Displays (AFD C&D).

Equipment noted with an asterisk (*) is described and illustrated in this subsection.

Versatile Service Stage - Satellite Placement and Retrieval

A Versatile Service Stage (VSS) is used to transport and retrieve satellites from higher energy LEO orbits that are not directly accessible by the Orbiter. It is equipped with a high performance propulsion system for performing large ΔV maneuvers, and a clean-firing, cold gas propulsion system for close-in satellite retrieval and Orbiter close proximity operations. The VSS contains a television system for satellite examination and to support remote control of the VSS-to-satellite docking/capture operation. Following capture, the VSS/satellite returns to the Orbiter and achieves rendezvous within about 1000 ft. Close proximity flight control of the VSS/satellite is remotely controlled by the Orbiter Crew who "fly" the VSS/satellite to within reach distance of the RMS arm (see Fig. 5-23).

Servicing of the satellite takes place on the Orbiter. Following servicing, the VSS/satellite is deployed from the Orbiter. The VSS then delivers the satellite to its operational orbit and again returns to the Orbiter.

Versatile Service Stage - Stabilizing Uncooperative Satellite

The Versatile Service Stage (VSS) is shown in Fig. 5-24 "snaring" a satellite that is known to be oscillating at rates higher than acceptable for direct docking by the VSS. A special front-end "kit," provided on the VSS, consists of an extensible mast and RMS snare end effector. The VSS would synchronize its motion with the satellite, extend the end effector to capture the satellite's RMS-compatible grapple fitting, and stabilize it for docking. The operation is remotely controlled via a TV link to the Orbiter (or ground).

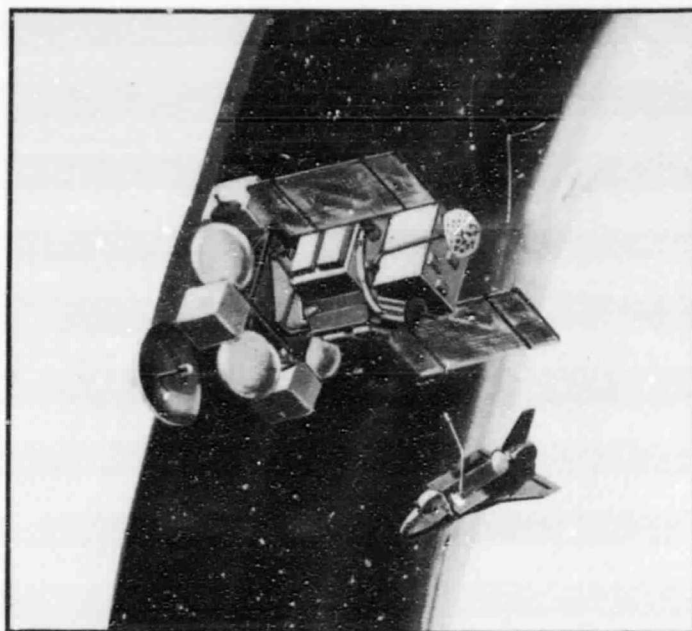


Fig. 5-23 Versatile Service Stage -
Satellite Placement & Retrieval

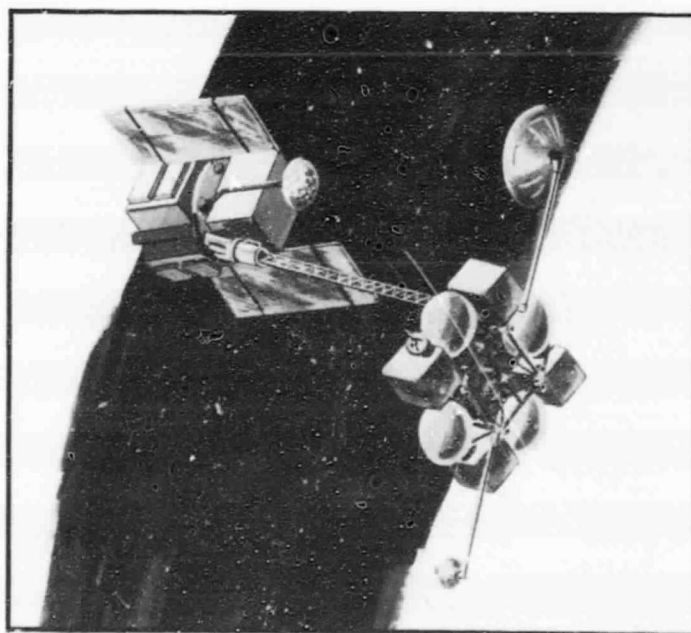


Fig. 5-24 Versatile Service Stage -
Stabilizing Uncooperative Satellite

5.6 Earth Return Equipment

Satellite service equipment associated with earth return operations includes:

- Special Retention Structures
- Equipment Storage
- Versatile Service Stage (VSS)*
 - Debris Capture Kit
 - o Debris Retrieval/Return to Orbiter
 - o Debris Deorbit
- Aft Flight Deck Controls/Displays* (AFD C&D).

Equipment noted with an asterisk (*) is described and illustrated in this subsection.

Versatile Service Stage - Capture of Satellite Debris

Figure 5-25 shows the Versatile Service Stage (VSS) adapted with a special front-end "kit" to capture space debris for deorbit or return to the Orbiter. The front-end "kit" consists of dexterous manipulator arms mounted to a rotating platform.

Capture operations are remotely controlled via a TV link to the Orbiter (or ground). After rendezvous with the debris element, the VSS TV monitors its tumbling motion and is maneuvered to a position where the plane of the VSS rotating platform parallels the tumbling motion. The platform is then spun up to synchronize with the debris tumbling rate. Manipulators engage the satellite and gradually de-spin it via a clutch mechanism in the rotating platform. The debris satellite is then "cinched-up" against bumper stops and held for propulsion maneuvering. The VSS could return to the Orbiter or perform a propulsion maneuver to place the debris element in a desired reentry trajectory, then release the debris to deorbit while the VSS returns to the Orbiter.

Versatile Service Stage - Close Proximity Flight Control

Close proximity operations of a free flying VSS are controlled by the crew from the Aft Flight Deck of the Orbiter (see Fig. 5-26). The VSS would rendezvous within about 1000 ft of the Orbiter and be flown by the crew to within reach distance of the RMS arm. The VSS and its payload would be captured by the RMS and positioned on a support structure (such as the Handling and Positioning Aid) to enable servicing or preparations for earth return.

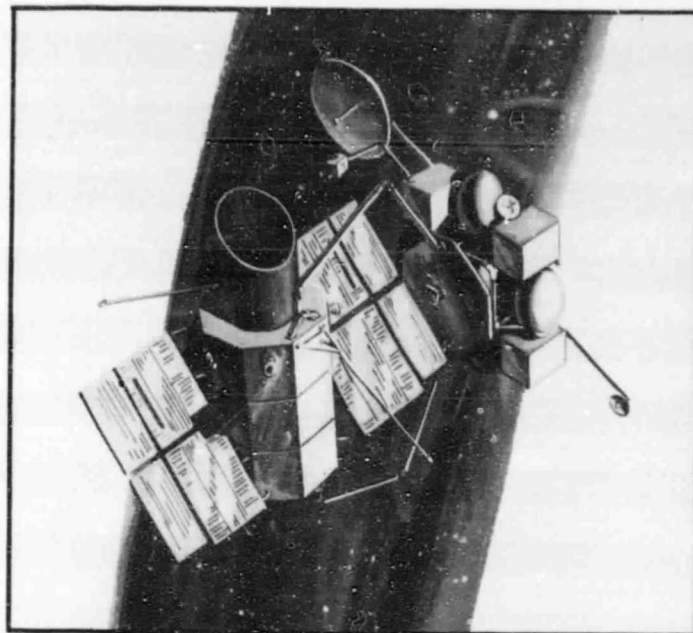


Fig. 5-25 Versatile Service Stage - Capture of Satellite Debris

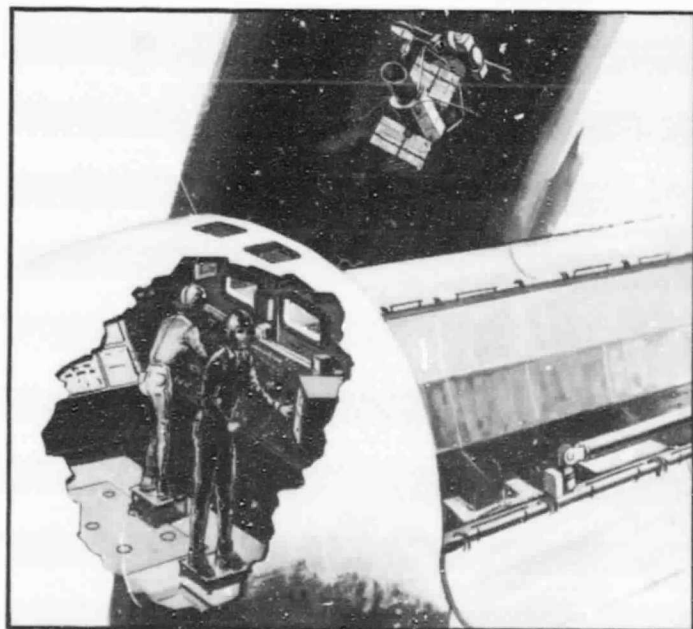


Fig. 5-26 Versatile Service Stage - Close Proximity Flight Control

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5.7 Optional Service Equipment

Satellite service equipment associated with optional on-orbit service operations, and which can be provided at the discretion of the satellite user, includes:

- Sun Shield*
- Orbital Storage*
- Attitude Transfer Package
- Lighting Enhancement.

Equipment noted with an asterisk (*) is described and illustrated in this subsection.

Sun Shield

The sun shield would provide sun-impingement protection to a satellite with the payload bay doors open. The shield would be retracted during launch and have the payload bay doors closed on-orbit. As the payload bay doors open, the shield closes automatically to envelope the payload as illustrated in Fig. 5-27.

As presently conceived, the large area surface of the sun shield would be composed of thin-film insulation and could be modularly adaptable to accommodate varying length satellite payloads. The deploy-on-orbit approach minimizes the unit's weight by eliminating the need for the shield to accommodate structural/vibration loadings during launch.

Figure 5-28 shows the sun shield retracted to enable deployment of a satellite by the RMS.

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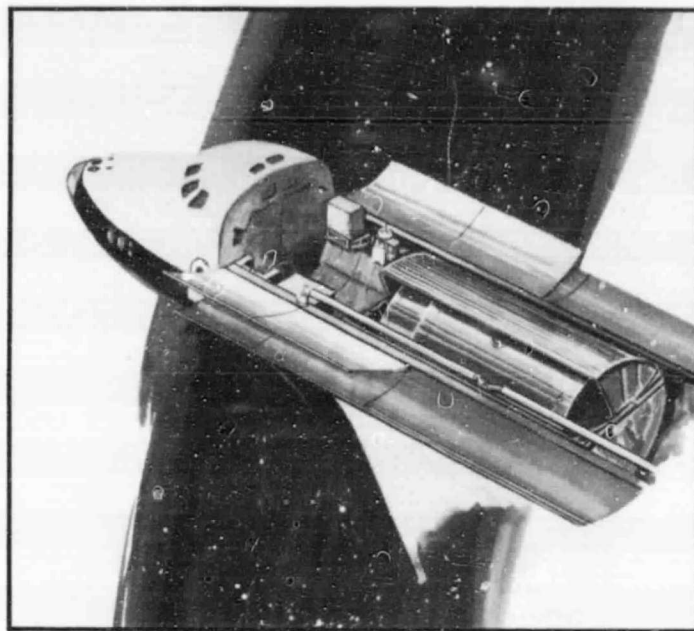


Fig. 5-27 Sun Shield – Enveloping Payload

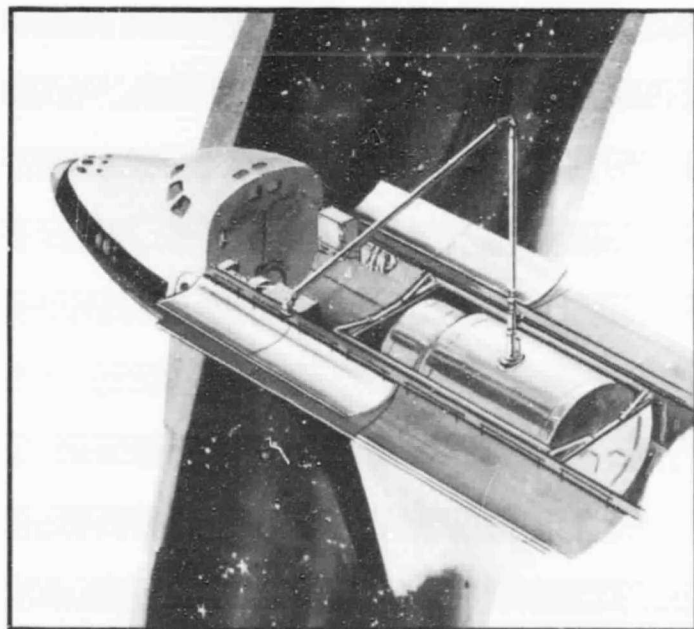


Fig. 5-28 Sun Shield – Open for Deployment

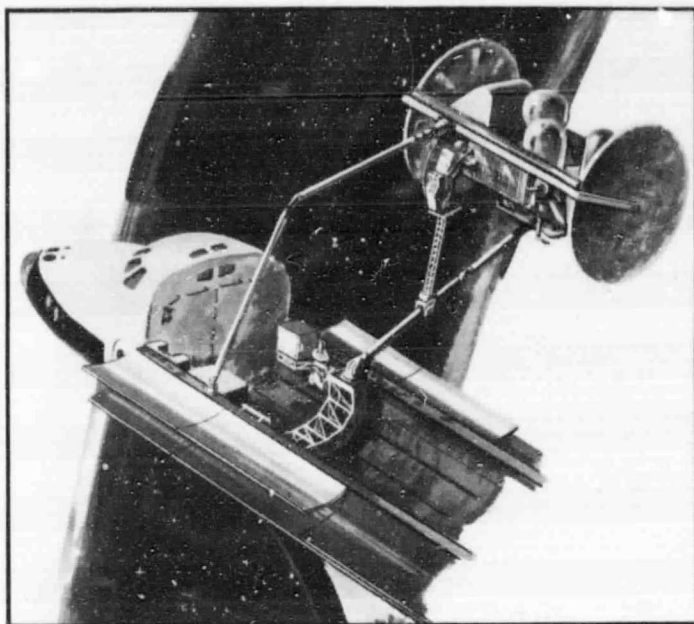


Fig. 5-29 Orbital Storage – Enclosure Placement

Orbital Storage

Orbital storage provides the option of leaving the spacecraft on-orbit for subsequent revisit/repair if a malfunction (detected prior to deployment) categorizes the satellite as non-operational. Orbital storage eliminates the need to carry backup spares (incurring added user charges) or to return a satellite to earth for repair and subsequent relaunch (additional user charges).

Mounted on the orbital storage enclosure is an RMS-compatible grapple fixture to enable transport from the payload bay to a satellite mounted on the HPA. Within the enclosure structure is an RMS snare-end effector which captures the satellite's grapple fixture and provides the enclosure's hard-point attachment to the satellite. Figure 5-29 shows the orbital storage enclosure being placed over the satellite by the RMS.

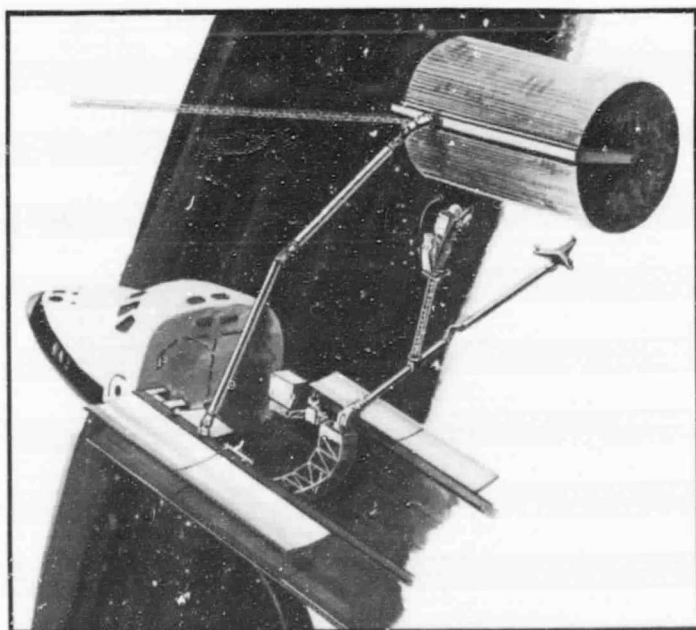


Fig. 5-30 Orbital Storage – Closure & Deployment

Figure 5-30 shows the satellite released from the HPA and raised above the HPA platform to allow closing of the storage enclosure. From this position, a gravity stabilization boom is activated to provide sufficient on-orbit stability to enable subsequent retrieval for repair/refurbishment of the satellite. With the boom deployed, the satellite is deployed by the RMS in its orbital storage mode.

The thermal enclosure concept employs thin-film insulation with activation of the end bulkheads and enclosure shell involving an inflation technique. The enclosure can also be modularly adaptable to accommodate varying length satellite payloads.

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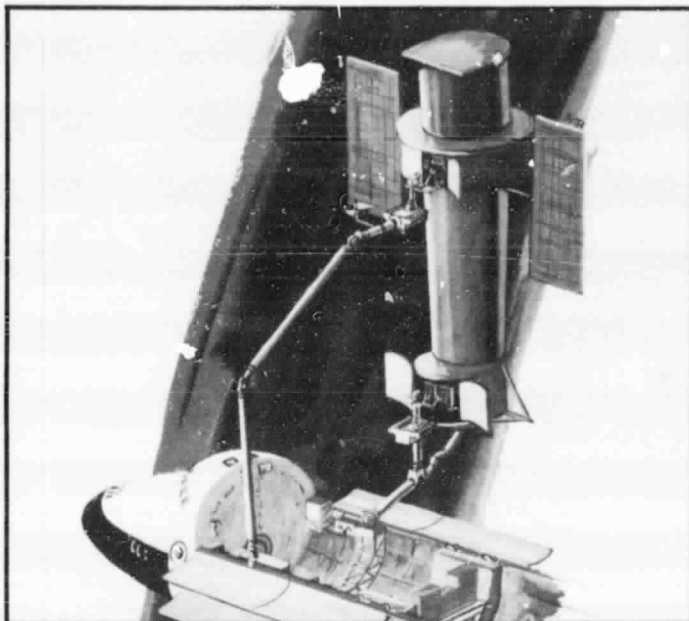


Fig. 5-31 Dexterous Manipulator – RMS Adaption

5.8 Advanced Capabilities Equipment

Satellite service equipment with the potential to come on-line within the next decade and which relates to on-orbit servicing includes:

- Dexterous Manipulators*
 - With Remote Manipulator System (RMS)
 - With Handling and Positioning Aid (HPA)
- Aft Flight Deck Controls/Displays (AFD C&D).

Equipment noted with an asterisk (*) is described and illustrated in this subsection.

Dexterous Manipulators

Dexterous manipulators for remote servicing operations can be expected once the technology has been suitably developed.

Figure 5-31 shows two dexterous manipulators, mounted on the end of the RMS arm, operated, and controlled by a master unit on the Aft Flight Deck. Dexterous manipulators can duplicate the motions of a human arm and shoulder, including sensing forces, and feed them back to the master. This concept enables remote, hazardous operations within the payload bay as well as servicing tasks.

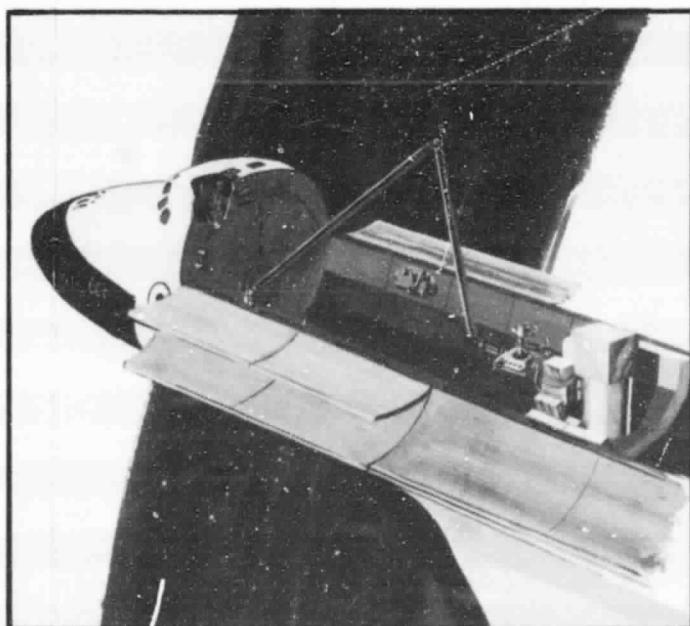


Fig. 5-32 Dexterous Manipulator – Dual Servicing Capability

Figure 5-32 depicts a dual adaptation of dexterous manipulators to service satellites. Remote servicing is performed with manipulators on the RMS and HPA work platform.

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6 - Assessment of Program Requirements

To scope the overall program and resources needed to develop and operate an SSS, a preliminary assessment of programmatic aspects was conducted covering the time period 1983 through 1993. The framework for development of the overall Satellite Services System cost estimate is the Work Breakdown Structure illustrated in Fig. 6-1.

Preliminary SSS program requirements have been identified based on the Satellite and Services User Model (S/SUM) as well as system and concept definitions developed during the study. Development schedules, costs, equipment utilization, and user charge information are amplified in Volume 5 (Programmatics) of this final report.

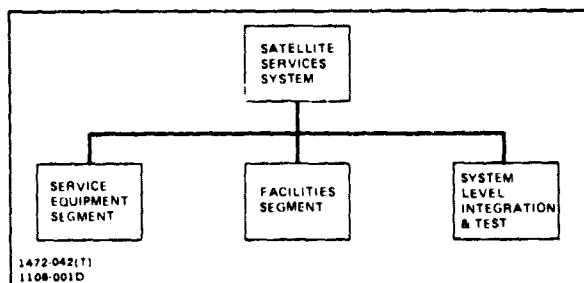


Fig. 6-1 Preliminary WBS – Satellite Services System

6.1 Service Equipment Needs/Usage

A summary of the near-term service equipment needs for calendar years 1983 through 1991 is shown in Fig. 6-2. Estimated annual usages are based on the mission events and related service equipment needs associated with the satellites/satellite classes in the S/SUM. Initial “driver” satellites/services, upon which the equipment need is founded, are also identified.

The earliest new hardware needs (1983) are for backup/contingency service equipment as the Manipulator Foot Restraint (MFR) and Work Restraint Unit (WRU) adaptations, and project high usage rates over the time period shown. The Flight Support System (FSS) also appears in 1983, is an existing element of satellite service hardware, and also projects reasonably high usage rates. A potential optional equipment need

is shown for the 1983 to 1985 time period (Attitude Reference Transfer Package) until that capability comes on-line with the Handling and Positioning Aid in 1986.

The Maneuverable Television (MTV) is identified as a 1984 need for Solar Maximum Satellite retrieval, with its extension to the Proximity Operations Module (POM) version called for in 1985. The Open Cherry Picker (OCP), its work platform adaptation to the FSS, and the Work Restraint Unit (WRU) POM-version are identified as potential needs for Solar Maximum Satellite retrieval in 1984. (Note that this Solar Maximum mission refers to a *planned* retrieval for earth return following an LDEF deployment, as opposed to a potentially-earlier Solar Maximum repair mission.) The Payload Installation/Deployment Aid (PIDA) is also identified as a 1984 need to support potential deployments of planetary payloads.

In addition to the POM-MTV adaptation need in 1985, two other equipment needs are identified; Equipment Stowage Provisions, and the Non-contaminating Attitude Control System. Both items of equipment, as well as the Fluid Transfer System identified for 1986 (and subsequent), are highly dependent upon the type of satellite(s) being serviced. Considerably more detail about the satellites and their servicing modes will be needed to define this equipment then is presently available.

The Handling and Positioning Aid is identified as a 1986 (and subsequent) need and projects very high utilization rates. This item of service equipment could represent the key element in standardizing on-orbit operations, checkout, and interfaces with prospective satellites for initial launch, revisit, and earth return service missions.

Finally, the Versatile Service Stage (VSS) is shown in Fig. 6-2 as coming on-line in 1987 to support the deployment/retrieval of LEO/Propulsion class satellites (those above the nominal delivery altitude of the Orbiter). Within this class of satellites, the VSS will eliminate the need to design integral propulsion

NEED	EQUIPMENT	MISSION USAGE	INITIAL DRIVER	ESTIMATED USAGE								
				'83	'84	'85	'86	'87	'88	'89	'90	'91
'83	• MANIPULATOR FOOT RESTRAINT (MFR)	L, E	BACKUP LATCH REL	21	45	56	82	75	78	76	76	72
	• WORK RESTRAINT UNIT ADAPTATIONS (MMU/WRU)	L, R, E	BACKUP TO RMS	24	51	67	99	101	108	111	114	106
	• ATTITUDE REFERENCE TRANSFER PACKAGE	L	POTENTIAL PAY LOAD NEED	2	7	7						
	• FLIGHT SUPPORT SYSTEM (FSS)	L, E	LANDSAT, CHEM REL MOD	2	5	5	24	28	25	25	36	28
'84	• MANEUVERABLE TV (MTV)	R, E	} SOLAR MAX RETRIEVAL		3	3	8	18	21	26	32	31
	• OPEN CHERRY PICKER (OCP)	R, E			1	1	6	12	16	20	22	20
	• FSS OCP WORK PLATFORM	R, E			1	1	3	1	1	1	1	-
	• PROXIMITY OPS MODULE (POM) – MMU/WRU ADAPTATION	R, E		2	1	4	22	3	3	5	6	
	• PAYLOAD INSTALLATION/DEPLOYMENT AID (PIDA)	L, E	PLANETARY PAY LOADS		3	3	7	6	5	6	6	6
'85	• EQUIPMENT STOWAGE PROVISIONS	R	SP TELESCOPE			1	3	11	15	19	21	20
	• NON-CONTAM ACS	R, E	} ST, LDEF			2	5	5	5	5	6	13
	• PROXIMITY OPS MODULE (POM) – MTV ADAPTATION	R, E				1	3	11	14	8	8	3
'86	• FLUID TRANSFER SYSTEM	R	LANDSAT, GRO				2	11	15	19	21	20
	• HANDLING & POSITIONING AID (HPA)	L, R, E	VERY MANY				55	66	71	75	78	74
'87	• VERSATILE SERVICE STAGE (VSS)	L, R, E	MANY					9	11	20	22	23

L = INITIAL LAUNCH
R = REVISIT
E = EARTH RETURN

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Fig. 6-2 Service Equipment Needs/Usage

systems to enable servicing or earth return by the Orbiter.

6.2 Funding Schedules

A ROM estimate of total Satellite Services System program costs was generated covering the 10 year period from 1983 to 1993. The estimate was based on available service equipment/concept definitions and included the production quantities assumed necessary to satisfy the service events projected in the S/SUM. The estimated costs associated with the major SSS WBS segments (see Fig. 6-1) are:

	1980 \$ (M)
• Service Equipment	649
• Facilities	4
• System Level Integration/Test	170
Total	823

The estimated funding schedule is shown in Fig. 6-3 which amplifies the DDT&E, production, operations, and annual/total program cost estimates. The schedule reflects service events projected in the S/SUM model, assumptions of various equipment usage for each service event.

and service equipment production quantities over the 10 year time frame.

Service equipment hardware items are considered as key generic elements in the SSS and are needed early in the program to provide viable services to the user community. These include:

- Backup/Contingency Equipments
 - Manipulator Foot Restraint (MFR)
 - Work Restraint Unit (WRU) Adaptations
- Close Proximity Retrieval Equipments
 - Maneuverable Television (MTV)
 - MTV-Proximity Operations Module
 - WRU-Proximity Operations Module
- On-Orbit Servicing Equipments
 - Open Cherry Picker (OCP)
 - Flight Support System - OCP Work Platform
 - Handling and Positioning Aid (HPA).

An estimate of DDT&E and TFU (Theoretical First Unit) costs was prepared for these "core service equipment items" and is shown in Fig. 6-4. As illustrated, the initial core equipment elements could be brought on-line in a 4 to 5 year period within a nominal funding limitation of approximately \$50 million.

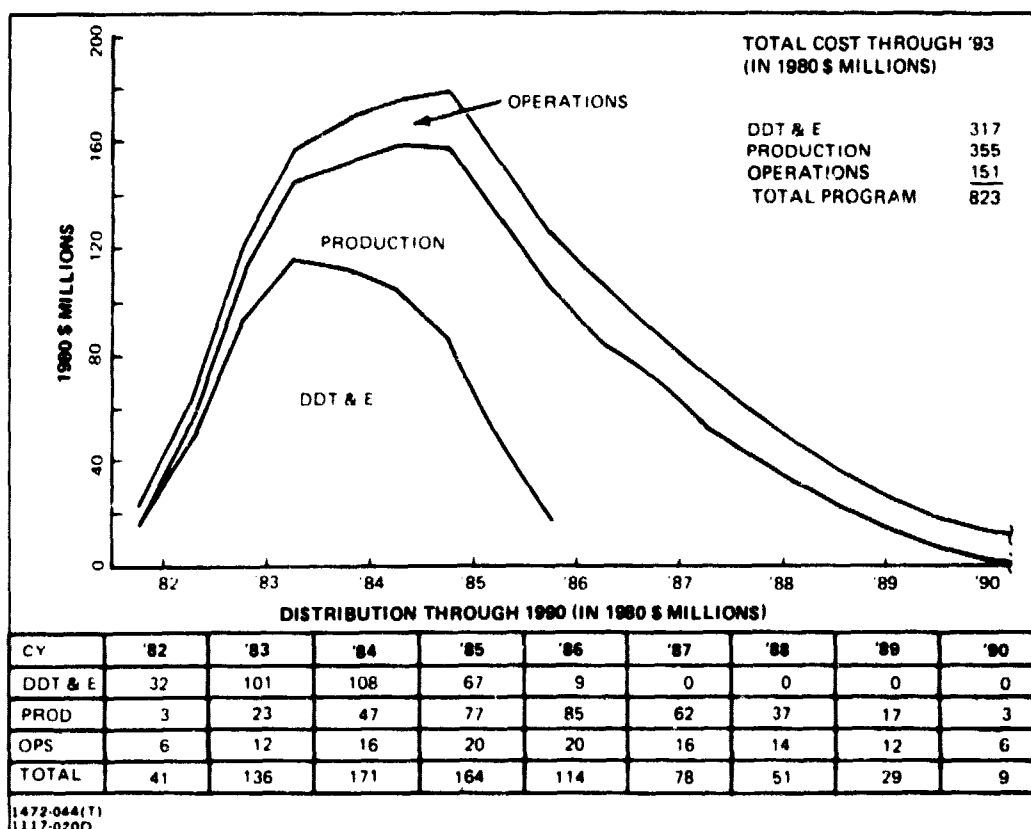


Fig. 6-3 Satellite Services System Funding Schedule

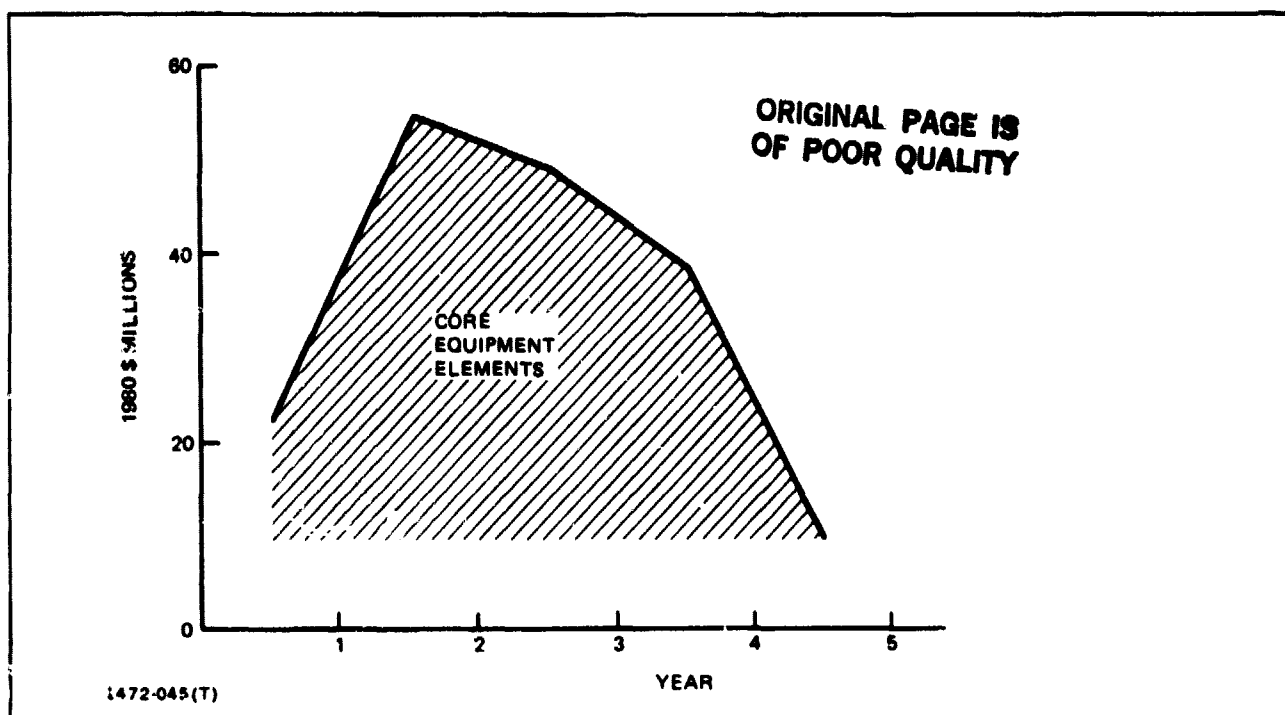


Fig. 6-4 "Core Service Equipment" - DDT&E/TFU Spreads

6.3 Representative Missions - Service Costs

Satellite services user costs are the sum of the equipment use charge, miscellaneous service charges, and the STS transportation charges for service equipment utilized on a particular mission manifest. User costs were assessed for four representative service missions:

- UARS Launch
- UARS Revisit
- SMM Earth Return
- AXAF Revisit.

The service equipment complements assumed for these missions are shown in Fig. 6-5

The UARS Launch mission reflects a typical complement of service equipment for a satellite deployment including primary and backup service equipment.

The UARS Revisit represents a LEO/Propulsion satellite class service mission in which the satellite's LEO operational altitude is above the nominal

delivery altitude of the Orbiter. The Versatile Service Stage is used to retrieve, and subsequently return, the satellite to its operational orbit after servicing at the Orbiter.

The SMM Earth Return illustrates a complement of service equipment for an earth return mission. The Orbiter would rendezvous with the satellite to about 1000 ft distance, and retrieval is accomplished by a POM-WRU adaptation.

The AXAF Revisit represents a service mission involving a contamination sensitive satellite. The Orbiter would rendezvous with the spacecraft to within 1000 ft and retrieval is accomplished by a POM-MTV adaptation.

For each mission, service equipment was packaged within the Orbiter payload bay and transportation charges were determined for the appropriate length/weight of the service equipment. User charges for the required service equipment were calculated and each mission was assessed in terms of miscellaneous charges including impact to

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SERVICE MISSION	SERVICE EQUIPMENT COMPLEMENT
UARS LAUNCH	<ul style="list-style-type: none"> • FLIGHT SUPPORT SYSTEM • MANIPULATOR FOOT RESTRAINT • MANNED MANEUVERING UNIT • WORK RESTRAINT UNIT - END EFFECTOR ADAPTATION • HANDLING AND POSITIONING AID • REMOTE MANIPULATOR SYSTEM
UARS REVISIT	<ul style="list-style-type: none"> • VERSATILE SERVICE STAGE • FLUID TRANSFER SYSTEM • HANDLING AND POSITIONING AID • MANEUVERABLE TELEVISION • OPEN CHERRY PICKER • MANNED MANEUVERING UNIT • WORK RESTRAINT UNIT - END EFFECTOR ADAPTATION • REMOTE MANIPULATOR SYSTEM
SMM EARTH RETURN	<ul style="list-style-type: none"> • FLIGHT SUPPORT SYSTEM • MANEUVERABLE TELEVISION • OPEN CHERRY PICKER • MANNED MANEUVERING UNIT • PROXIMITY OPERATIONS MODULE - WRU ADAPTATION • REMOTE MANIPULATOR SYSTEM
AXAF REVISIT	<ul style="list-style-type: none"> • HANDLING AND POSITIONING AID • FLUID TRANSFER/EQUIPMENT STOWAGE • NON-CONTAMINATING ACS • PROXIMITY OPERATIONS MODULE - MTV ADAPTATION • OPEN CHERRY PICKER • MANNED MANEUVERING UNIT • WORK RESTRAINT UNIT - END EFFECTOR ADAPTATION • REMOTE MANIPULATOR SYSTEM

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Fig. 6-5 Representative Service Missions & Equipment Complements

KSC flow, EVA requirements, days on orbit, and payload specialist usage.

Figure 6-6 shows the dominant user charge for satellite services to be the STS transportation charges for the service equipment. Miscellaneous service charges are moderate and equipment usage charges (amortized as a function of total

estimated usage) are minimal. The overall service costs appear about equal for initial launch, revisit, and earth return missions.

Of key significance, however, is the fact that total user charges for revisit missions appear to be about 5-10% (or less) of the cost to build and relaunch a replacement satellite. Obviously, this indicates that satellite servicing from the Orbitor is cost effective!

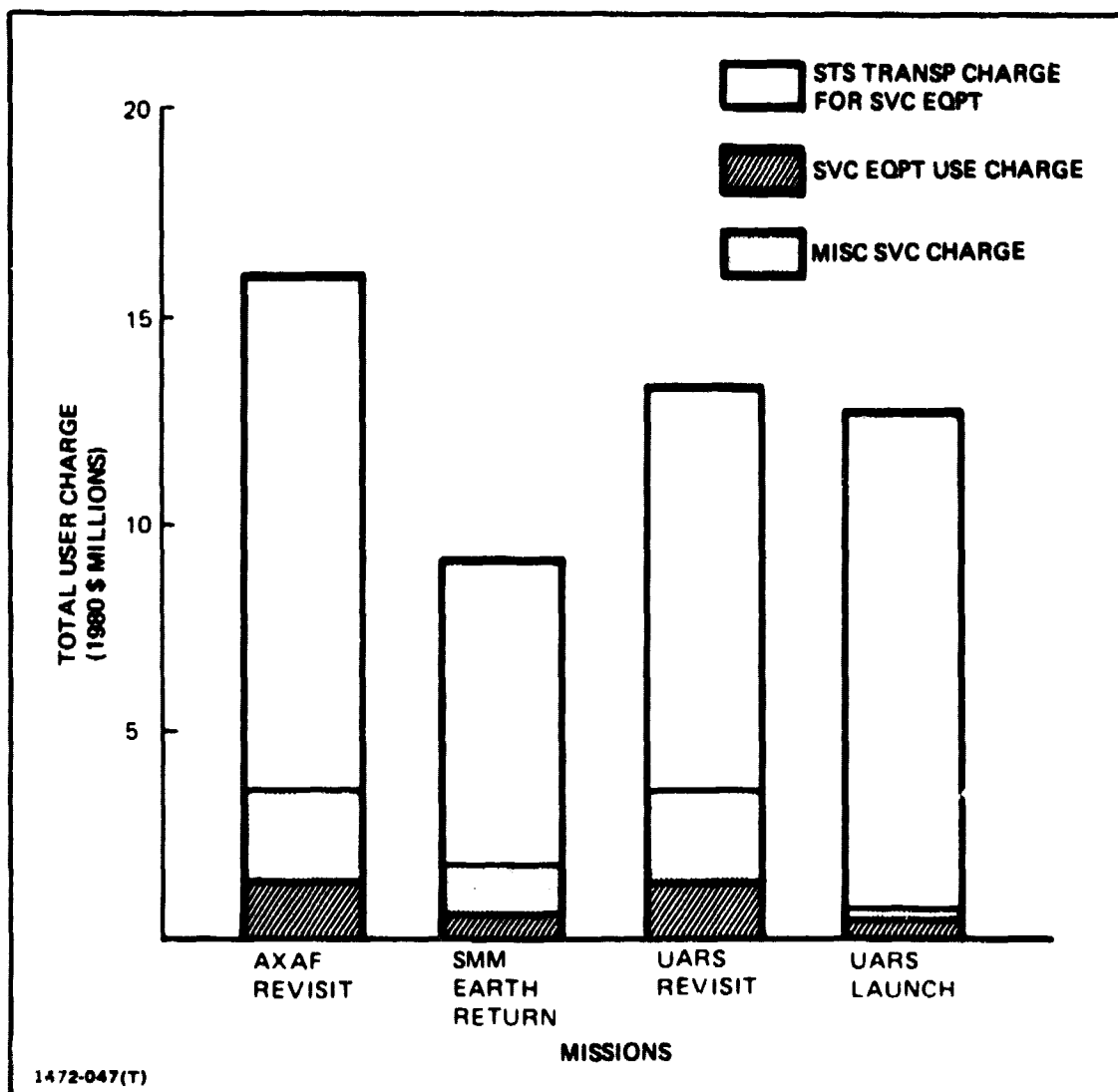


Fig. 6-6 Representative Missions - Service Costs

* Production and system integration costs for SMM and AXAF were estimated at \$150M and \$200M, respectively.

7 - Conclusions / Recommendations

7.1 Conclusions

Overall conclusions derived from this Satellite Services System Analysis Study are as follows:

- Considerable service needs are projected for the decade of the 1980's with continued growth into the 1990's and beyond. Exclusive of initial launch/deployment, the need for revisit services begins to accelerate in 1986
- Revisit and earth return services should be planned for Orbiter flights after initial launch/deployment of satellite payloads has been accomplished
- On-orbit manned involvement will be an inherent part of satellite services in both primary and contingency service operations
- Considering a broad spectrum of potential servicing scenarios and satellite classes, twenty-seven items of service equipment were identified. The present status of the equipment is as follows:

Existing	6
Under Development or Study	5
Modifications	3
New	12*
Unique	1
Total	27

(*Four are optional.)

- The Handling and Positioning Aid (HPA) could be a key equipment element in standardizing on-orbit operations, checkout, and interfaces with prospective satellites
- Most equipment identified reflects high usage rates through 1990. Service equipment that indicates usage greater than 100 through that time period includes:
 - Manipulator Foot Restraint (MFR)
 - Handling and Positioning Aid (HPA)
 - MMS-Flight Support System (FSS)
 - Aft Flight Deck Controls/Displays (AFD-C&D)
 - Manned Maneuvering Unit/Work Restraint Unit Variations (MMU/WRU)

- Maneuverable Television (MTV)
- The "core service equipment" could be brought on-line in a 4-5 year period within modest funding levels
- Satellite services are cost effective
 - Service costs, which include equipment usage and transportation charges for service equipment, appear about equal for initial launch, revisits, and earth return service events
 - Revisit charges are estimated at about 5-10% (or less) of the cost to build and relaunch a replacement satellite.

7.2 Recommendations

Satellite servicing from the Orbiter is a cost-effective and viable extension of the capabilities of the Space Transportation System (STS). To enable the satellite user community to avail itself of this inherent and near-term STS capability, it is recommended that a central program office be established to coordinate satellite service activities.

Standardization of on-orbit service operations from the Orbiter is also recommended. The physical interface (berthing, electrical, fluid) between satellites and the Orbiter should be standardized, as well as spacecraft checkout operations and their related Aft Flight Deck controls/displays. Efforts toward bringing about this standardization, in conjunction with the user community, is a near-term STS necessity to preclude the proliferation of single-purpose, satellite-unique service equipment.

Generic "core service equipment" should be developed as soon as possible to enable satellite users to effectively plan for its use. Early flight demonstration of this service equipment and its operation is recommended to provide proof-of-capability to the satellite user community.

Considering the propellant usage associated with Orbiter close proximity operations, potential overpressure and contamination effects on satellites and the legitimate concerns of contam-

ination sensitive users, it is recommended that satellite retrieval operations be conducted with the Orbiter in standoff position and retrieval accomplished by manned or unmanned Proximity Operations Modules.

Additionally, the nature of the contamination environment in the vicinity of the Orbiter payload bay should be determined and its acceptability to contamination-sensitive users assessed. The issue to be resolved is the need for a non-contaminating attitude control system aboard the Orbiter during satellite servicing.

Backup/contingency situations should be considered for on-orbit satellite service operations. It is recommended that the payload retention latches of the Orbiter be redesigned to permit manual release of the satellite in case of a mechanical hangup during satellite deployment operations.

Service equipment use charges are a minimal cost item associated with a service event. These charges are the result of recovery of equipment production costs as a function of total usage. In

view of their minimal effect on service costs, it is recommended that this equipment use charge be "absorbed" within the overhead operations of the STS, and the services and equipment be made available to the user community as part of the standard features of the Space Shuttle.

Servicing operations performed from the Orbiter will provide the operational experience base and service equipment hardware to confidently extend servicing operations to the next step, in terms of further reducing future service costs to the user community. Since the major user service charge is transporting the service equipment to orbit, it would make sense (in the future) to deliver the equipment to orbit once to eliminate the repeat transportation charges. This suggests that a permanent service platform, or space station, would be a logical place from which to conduct future satellite servicing operations. It would appear that permanent space operations centers could be economically viable in orbital inclinations which anticipate high satellite traffic (e.g. $28\frac{1}{2}$ deg). Additional studies of this operational servicing approach are, therefore, recommended.